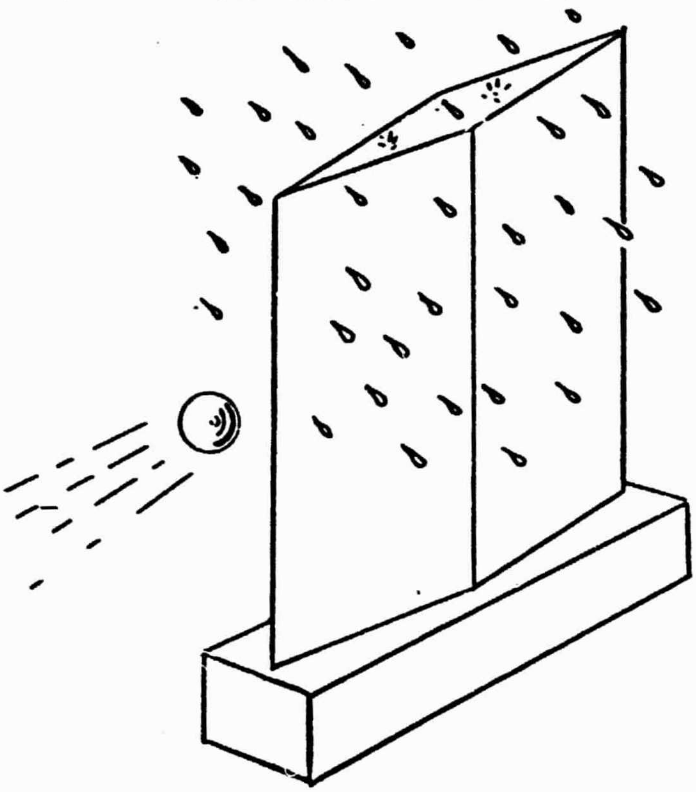
NASA-CR165211

R81AEG694

National Aeronautics and
Space Administration

ENVIRONMENTAL EFFECTS ON FOD RESISTANCE OF COMPOSITE FAN BLADES

CONTRACT NAS3-21017



FINAL REPORT
JANUARY 1981

By

General Electric Company
Aircraft Engine Group
Cincinnati, Ohio 45215

Prepared for

National Aeronautics and Space Administration
NASA-Lewis Research Center

(NASA-CR-165211) ENVIRONMENTAL EFFECTS ON FOD RESISTANCE OF COMPOSITE FAN BLADE Final Report (General Electric Co.) 274 p HC A12/MF A01 CSCL 11D

N81-33236

Unclas
G3/24 27558

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA-CR165211		

4. Title and Subtitle	5. Report Date
ENVIRONMENTAL EFFECTS ON FOD RESISTANCE OF COMPOSITE FAN BLADES	January 1981
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
G.C. MURPHY/C.T. SALEMME	R81AEG694
	10. Work Unit No.
9. Performing Organization Name and Address	11. Contract or Grant No.
GENERAL ELECTRIC COMPANY NEUMANN WAY CINCINNATI, OHIO 45215	NAS3-21017
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	CONTRACT REPORT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

PROJECT MANAGER, GORDON SMITH
NASA-LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44˜35

16. Abstract

This program was undertaken to establish the sensitivity of the impact characteristics of typical polymeric composite fan blade materials to potential limiting combinations of moisture, temperature level and temperature transients.

The technical effort reported herein comprised of four technical tasks conducted in series.

Task I - Evaluation and Characterization of Constituent Blade Materials

Basic laminated materials were subjected to environmental conditions of "dry", "wet" and "wet spike" to assess the effect on laminate mechanical properties.

Task II - Ballistic Impact Tests

Simulated small scale airfoil like specimens were fabricated, from hybridized versions of the basic Task I materials in addition to a superhybrid construction and ballistically impacted with gelatin projectiles after environmental conditioning.

Task III - Leading Edge Impact Protection Systems

Larger size hybrid and superhybrid airfoil specimens with a leading edge protection device were fabricated, environmentally conditioned and ballistically impacted with a starling size gelatin "bird".

Task IV - Simulated Blade Spin - Impact Tests

Dynamic impact testing using a rotating simulated airfoil specimen was originally planned but moisture sensitivity of the specimen/rig adaptor adhesive caused the cancellation of the spin tests.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Superhybrid Composites Hybrid Composites Impact Testing Fan Blades Environmental Effects Moisture Degredation	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED	284	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

NASA-C-168 (Rev. 6-71)

FOREWORD

This Final Technical Report covers work performed under Contract NAS3-21017 from 2 July 1977 to 31 December 1980. The work was accomplished under the Technical Direction of Mr. Gordon Smith, Project Manager, National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

Mr. Al Wilson of the General Electric Company was the Program Manager and Mr. Guy C. Murphy was the Technical Project Manager and author of this report.

Principle contributors to the General Electric activities described in this report were: Mr. C.T. Salemme, Design and Impact Test & Coordinator; Mr. J. Jones, Specimen Fabrication; Mr. Glen Huber, Cincinnati Testing Laboratories, Mechanical Properties Testing and Sepcimen Conditioning; and Mr. G.J. Roth and R. Bertke, University of Dayton, Ballistic Impact Testing.

TABLE OF CONTENTS

IV

PRECEDING PAGE BLANK NOT FILMED

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Concluded)

1.0 SUMMARY

The work presented in this report presents the results of a forty-two month program aimed at determining the environmental effects on the foreign object damage (FOD) resistance of composite fan blades.

The basic objectives of the program were to determine the combined effects of moisture, temperature, and temperature transients on the impact resistance of various composite fan blade material/construction concepts.

The program was basically divided into four technical tasks.

Task I - Evaluation and Characterization of Constituent Materials

The effect of moisture and temperature was evaluated on the mechanical properties of typical basic constituent fan blade materials. The materials evaluated included combinations of two epoxy matrices, PR288 and SP313; one polyimide resin system, NR150A2 and two fiber reinforcements, T300 graphite fiber and 1014 S-glass. Flexural and short beam shear tests, in both the longitudinal and transverse directions, were evaluated on unidirectional specimens conditioned to a fully moisture saturated and nominally "dry" state. Fully wet specimens were also tested with an abrupt temperature excursion to 422 K (300° F) ("wet spike"). The "dry" conditioning, which was the equivalent of long-term storage at 294 K (70° F) relative humidity, had no effect on the fully dry condition properties of the laminates when tested at 294 K (70° F) and 394 K (250° F). There was a negligible effect on the T300 by wet or wet spike conditioning when tested at 294 K (70° F). The S-glass laminate properties were, however, reduced by thirty percent. Elevated temperature tests illustrated the plasticizing effect of the absorbed moisture on the lower temperature capability matrices. PR288 laminates retained only 40 to 50 percent of their "dry" 394 K (250° F) properties. The higher temperature matrices, SP313 and NR150A2, showed reduced fall-off in mechanical properties since the 394K (250° F) test temperature was below the resin glass transition temperatures (Tg). The extreme moisture resistance of the NR150A2 system was demonstrated absorbing only nominally 30 percent of the moisture typical of the two epoxy systems. The NR150A2 composite systems exhibited extremely high transverse flexural properties of almost double the values of the epoxy laminates.

Task II - Ballistic Impact Tests

The effects of temperature, moisture and temperature transients on the ballistic impact resistance of selected composite materials were evaluated during this task. Task I basic materials were combined to form three intraplied hybrid systems PR288/T300/S, SP313/T300/S, and NR150A2/T300/S and two superhybrid systems using PR288/T300/S and SP313/T300/S core material with

external laminae of titanium and boron-aluminum foils. PR288/T300 was also included as a nonhybridized baseline system. Eighty simulated airfoil specimens were fabricated from the various material/design configurations and after environmental conditioning were ballistically impacted at 25° incidence angle with gelatin projectiles at velocities ranging from 180 m/sec (590 ft/sec) to 270 m/sec (886 ft/sec).

The superhybrid specimens exhibited superior resistance to impact damage at all levels of test temperatures and conditioning. The external metallic foils acting as moisture barriers preventing degradation of the polymeric composite core and foil bonding adhesives. The NR150A2 polyimide hybrid system exhibited superior resistance to ballistic impact damage compared to the equivalent two epoxy systems. There was a slight indication that the "hot wet" condition improved the damage tolerance of the PR288 composite systems. The viscoelastic effect of the moisture plasticized matrix is believed to have contributed to the reduced damage level.

Task III - Leading Edge Impact Protection Systems

One hybrid and one superhybrid system was selected from Task II and larger simulated airfoil specimens were fabricated and reinforced with a leading edge protection device prior to environmentally conditioning and conducting ballistic impact tests. Initially, NR150A2/T300/S was the selected hybrid system but due to processing problems and DuPont withdrawing the NR150 materials from the market, the PMR15 NASA developed polyimide system was finally substituted. The more moisture resistant SP313/T300/S system was selected as the core material for the superhybrid specimens. A nickel plated wire mesh was selected as the leading edge protection system. Multiple impacts were conducted on each specimen to determine the threshold damage level for each design and environmental condition. Impact velocities ranged from 120 m/sec (394 ft/sec) to 275 m/sec (902 ft/sec) utilizing a larger simulated starling size gelatin "bird".

Premature failure of the protection device which overshadowed the test results, was primarily caused by moisture degradation of the adhesive used to bond the wire mesh to the specimens.

Composite damage was basically combined to the exposed trailing edge zone of the specimens. The superhybrid design specimens exhibited superior impact resistance at all test temperatures and environmental conditions.

Task IV - Simulated Blade Spin Tests

The original plan in Task IV was to dynamically impact similar Task III static impact design specimens on a spin test facility. Four specimens of each hybrid and superhybrid design were fabricatred and prepared for spin impact testing in the "dry" and "wet spike" condition at 294 K (70° F) and 394 K (250° F) respectively. The specimens were designed with an attachment feature for mounting to a rotating disk facility. Specimen to rig adaptor

bonding studies disclosed that the adhesive (Metlbond 328) was extremely sensitive to moisture degradation and even when the bondline was sealed with RTV rubber, the strength properties of the adhesive were too low to withstand the bond shear stresses during the spin test. The spin tests were finally eliminated from the program.

2.0 INTRODUCTION

The fan blades of a high-bypass turbofan engine constitute a high proportion of the overall engine weight because of their physical size. Composite fan blades have the potential for affording many advantages over the current metal counterpart, especially in the areas of cost, weight, efficiency, and maintainability.

Over the last ten years many composite fan blade research programs have been conducted to provide materials development, design concepts, and analysis procedures needed for the application of composite materials to turbine engine fan and compressor blades. A variety of fibers, matrix materials, and localized reinforcement concepts have been investigated and evaluated with respect to impact energy absorption capacity and resistance localized impact damage. Effective application of the most promising of these materials to turbine engine fan blades is dependent on the ability of these materials to maintain an adequate level of impact damage resistance during and after exposure to environmental conditions typical of aircraft operations. Resin matrix properties have been shown to be degraded by certain moisture-temperature combination exposures. The purpose of this program was to establish the sensitivity of the impact resistance characteristics of composite blade materials to limiting combinations of moisture, temperature level, and temperature transients. The program was divided into four technical tasks.

Task I - Evaluation and Characterization of Constituent Blade Materials

The task involved the investigation of the effects of moisture content, temperature level, and temperature transients on the longitudinal and transverse short beam and flexural strengths of specific fiber/resin basic composite laminates. Combinations of three different resin systems and two fiber reinforcements were studied. Specimens were tested in both the fully wet and nominal dry conditions. The fully wet specimens were tested with and without an abrupt temperature excursion to 422 K (300° F). The materials evaluated included two epoxy resin matrices, PR288 and SP313, and one polyimide resin system, NR150/A2. The two fiber reinforcements selected for evaluation were the T300 graphite fiber and the 1014 S-glass.

Task II - Ballistic Impact Tests

The effects of temperature level, moisture, and temperature transients on the ballistic impact resistance of selected composite fan blade materials were evaluated during this task. Candidate materials based on the results of Task I were combined to form three hybrid and two superhybrid systems in addition to a baseline PR288/T300 system. Eighty simulated, nine-inch-long blade specimens employing a constant double wedge section of three inches

chord were fabricated and ballistically impacted. Gelatin projectiles were fired at relative velocities and impact angles to simulate local impact forces and stresses on the panels typical of bird impact. The environmentally conditioned specimens were tested at 219 K (-65° F), 294 K (70° F), and 394 K (250° F). Evaluation of the impact damage was carried out by nondestructive inspection, change in torsional stiffness, in addition to visual observations and high speed motion pictures of selected tests.

Task III - Leading Edge Impact Protection Systems

Based upon the ballistic impact test results of Task II, one hybrid and one superhybrid system were selected and used for the fabrication of simulated blade panels which were reinforced with leading edge protection devices. One specific leading edge (nickel plated wire mesh) protection system was selected for impact testing evaluation. The 20 simulated blade specimens, six inch chord and 16 inches nominal length, were moisture conditioned and ballistically impacted 219 K (-65° F), 294 K (70° F) and 394 K (250° F) using one-inch-diameter projectiles fired at velocities of ~1000 feet per second.

Task IV - Simulated Blade Spin - Impact Tests

The results of Tasks II and III were used to select material combinations and leading edge protection systems which possess the most promising environmental resistance and impact resistance characteristics for spin impact testing. One of each of the selected combinations represented a hybrid and superhybrid design reinforced in the leading edge area with a selected protection device established from Task III. The specimen design was similar to that used in Task III except for the attachment feature for mounting to the rotating disk assembly. A total of eight specimens, four of each design, were fabricated. The dynamic spin impact tests were finally eliminated due to adverse moisture effects on the adhesive used to bond the specimens to the rig adaptor shoes.

3.0 TASK I - EVALUATION AND CHARACTERISTICS OF CONSTITUENT MATERIALS

The Task I portion of the program investigated the effects of moisture content, temperature level, and temperature transients on the longitudinal and transverse short beam shear and flexural strengths of specific fiber/resin composite laminates. The task involved the fabrication and testing of three different resin systems and two different fiber combinations. The specimens were tested in both the fully wet and nominally dry conditions. The nominally dry condition corresponded to a moisture content acquired by prolonged exposure to 50 percent RH and 294 K (70° F) storage conditions. The fully wet specimens were tested with and without an abrupt temperature excursion to 422 K (300° F) (wet spike) immediately before being subjected to the test environment.

3.1 MATERIAL SELECTIONS

Three different resin systems and two different fibers were evaluated during Task I. The resins comprised of two epoxy and one polyimide and the fiber reinforcements consist of graphite and S-glass, resulting in a total of six combined composite systems.

3.1.1 Resin Matrices

PR288 was designated by NASA, based upon previous General Electric recommendations, as one of the epoxy matrix materials to be evaluated in this task. An industry search was carried out to select a second epoxy resin and a polyimide system for evaluation in the program. The SP313 epoxy (3M Product) was finally selected based upon the following criteria:

- Improved moisture resistance compared to other available systems - Table I.
- Similar composite mechanical properties to PR288 - Table II.
- Neat resin properties similar to PR288.
- Common prepreg source (3M's) to ensure requisite quality and capability for producing hybrid materials required for subsequent tasks.

The DuPont NR150/A2 was selected as the polyimide matrix based upon the following conclusions:

- Processing technology was believed to be sufficiently advanced that quality laminates could be produced with minimum risk.
- Potentially improved impact resistance in view of the high resin elongation of ~8 percent.

Table I. *Flexural Strength Retention of SP313/T300 After 24 Hour Water Boil Conditioning.

Material System	Flexural Strength MPa (ksi) 294 K (70° F)	450 K (350° F)	450 K (350° F) After 24 Hr Water Boil	Percent Strength Retention
3M SP313/T300	1682 (244)	1407 (204)	1241 (180)	88
Narmco 5208/T300	1710 (248)	1455 (211)	1020 (148)	70
Hercules 3501/AS	1544 (244)	1269 (184)	883 (128)	69
Fiberite X934/AS	1600 (232)	1207 (175)	496 (72)	41

*Information received from 3M Company

Table II SP313 Comparative Composite Laminate Data.

Material System	0° Flexural Strength MPa (ksi)	0° SBS Strength MPa (ksi)	Comments
SP313/T300			
RT	1682 (244)	103 (15.0)	SBS L/D Ratio 4:1
450 K (350° F)*	1407 (204)	52 (7.5)	
PR288/T300			
RT	1613 (234)	101 (14.7)	
450 K (350° F)	1227 (178)	62.7 (9.1)	SBS L/D Ratio 5:1
PR288/AS			
RT	1600 (232)	109.6 (15.9)	SBS L/D Ratio 5:1
394 K (250° F)	1427 (207)	68 (9.9)	
PR288/AS(80)/S(20)			
RT	1503 (218)	105 (15.2)	
394 K (250° F)	1400 (203)	66 (9.6)	SBS L/D Ratio 5:1

*Note: Tested at 450 K (350° F).
Estimated SBS at 394 K > 69 MPa (250° F > 10 ksi)

- Low void contents feasible (<1 percent) which would yield optimum mechanical composite properties.

- Potentially high transverse strengths (DuPont data using AS fiber indicated 88.9 KPa (12.9×10^3 psi).

- NR150AG adhesives were available for metallic bonding/co-curing of superhybrid configurations required subsequent tasks. [Titanium 6-4 lap shear data 34 MPa (5 ksi) at RT, 19 MPa at 533 K (2.8 ksi at 500° F)].

- Thermoplastic above Tg [561 K (500° F)].

- Ultrasonic bonding potential for future fan blade/platform assemblies.

3.1.2 Fiber Reinforcements

The fibrous reinforcing materials designated by NASA for the Task I were Union Carbide's Thornel 300 intermediate modulus graphite and high strength S-glass fiber S-901 manufactured by Owens Corning.

3.1.2.1 Graphite Fiber

The Thornel 300 fiber was procured for combining with all matrix materials with the standard proprietary sizing/finishing developed by Union Carbide. Considerations were given to removing the "epoxy compatible" size off the fiber by heat cleaning before being combined with the polyimide system. Degradation of the epoxy size at the high processing temperatures of the NR150 was the major concern. Investigations and discussions with industry representatives indicated that a reduction in properties is evident by heat cleaning the T300 fiber rather than achieving improvements.

3.1.2.2 S-Glass Fiber

The 1014 S-glass manufactured by Ferro Corporation was employed throughout the program in lieu of the designated S-901 Owens Corning fiber. The 901 proprietary epoxy size requires refrigeration to prevent curing at room temperature and therefore, promotes difficulties in handling by the prepreggers during the setup time of the fiber tows and/or ends in the impregnation equipment. The low temperature cure of the 901 system may be unsuitable and incompatible with the high processing temperatures required for the NR150/A2 polyimide system. The 1014 S-glass is treated with the A1100 finish plus an epoxy compatible size which is stable at room temperature and, therefore, does not require refrigeration. The 1014 S-glass is the fiber which has been used exclusively in all the previous PR288 fan blade hybrid composite materials.

3.2 MATERIAL PROCUREMENT AND QUALITY ASSURANCE

3.2.1 Material Procurement

All the prepreg tapes were basically procured in accordance with the General Electric Specification 4013163-484, Rev. A, "Unidirectional Carbon, Graphite, S-Glass Fiber, Preimpregnated Tape or Wide Goods." The proprietary PR288 and SP313 resin matrix materials were supplied by Minnesota Mining and Manufacturing Comnpany (3M), St. Paul, Minnesota. The NR150A2 DuPont polyimide resin prepregs were produced by the Fiberite Corporation, Winona, Minnesota.

3.2.2 Material Quality Assurance

The six combinations of prepreg materials were subjected to establish Quality Control procedures which include sampling of the materials and verification of compliance with the specification requirements including physical properties of the prepreg and molded panels in addition to mechanical properties of the molded panel from each material combination. The Quality Control Data Summary for each material is shown in Tables III through VIII.

3.3 TEST PANEL FABRICATION

A series of 0° orientation test panels 30.5 cm x 30.5 cm x 2.03 mm (12 in. x 12 in. x 0.080 in.) were molded for producing the PR288 and SP313 test coupons. As a result of the high molding pressures established for processing the NR150A2 composites (and press availability), the test panels for this material were produced at a reduced size of 7.6 cm x 17.8 cm (3 in. x 7 in.).

3.3.1 Panel Molding and Curing Conditions

3.3.1.1 PR288 Composites

The PR288 matrix composites were molded and cured in accordance with the standard developed procedures.

- Mold at 383 K ± 2 K (230° F ± 5° F)
- Load mold and close to contact pressure down to 10 percent off closure shims in three minutes
- Maintain contact pressure for 35 minutes.
- Remove shims and commence closure down to stops.
- Attempt to reach closure in three minutes.
- Apply minimum of 2068 KPa (5171 KPa maximum) [300 psi (750 psi maximum)].

Table III. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-404)

Appendix B

Prepreg Lot No. 749 — Date Received 3/4/77

Prepreg Type PR288/S-Glass — Fiber Batch No. Ferro (S1014)

Quantity 18,144 gm (40 lbs) — Resin Batch No. 468-500

	Vendor	M&PTL	Spec.	*Requal.	Accept	Reject
A. Fiber Data:						
Tensile Str., MPa (ksi), Avg.	---	---	Min.			
Tensile Mod., GPa (msi), Avg.	---	---				
Density, gm/cc, Avg.	---	---				
B. Prepreg Data:						
Fiber, gm/m^2 (ft^2)*, Avg.	163 (17.0)	179 (16.6)	189.4 ± 0.005 17.6 ± 0.6			x
Individual Specimens**	5/6	0/6	2/3			x
Resin, gm/m^2 (ft^2), Avg.	80 (7.4)	79 (7.3)	78.5 ± 4.3, (7.3 ± 0.04)		x	
Individual Specimens**	6/6	6/6	2/3		x	
Vols., % Wt., Avg.	0.15	0.2	2% Max.		x	
Individual Specimens**	6/6	6/6	2/3		x	
Gel Time, Mins. 383 K (230° F)	60	55	40 Min.		x	
Flow, % 383 K (230° F)	---	---	---			
Visual Discrepancies						
C. Laminate Data:						
Roll No.(s)		1-1				
Gel Time in Die, Mins.		55	0.203 ± 0.005	0.200		
Thickness, cm (in.)		0.203 (0.080)	(0.080 ± 0.002)	(0.079)	x	
Flex. Str. at RT., MPa (ksi)	1641 (238)	1744 (253)	1448 (210)	1586 (230)	x	
394 K (250° F), MPa (ksi)	1048 (152)	1331 (193)	1172 (170)	1214 (176)	x	
Flex. Mod. at RT, GPa (msi)	48 (7.0)	53 (7.7)	44.8 (6.5)	52 (7.6)	x	
394 K (250° F), GPa (msi)	52 (7.5)	52 (7.5)	41.4 (6.0)	52 (7.58)	x	
SBS Str. at RT, MPa (ksi)	101 (14.6)	118 (17.1)	82.7 (12.0)	101 (14.[illegible])	x	
394 K (250° F), MPa (ksi)	62 (9.0)	69 (10.0)	51.7 (7.5)	51.7 (7.5)	x	
Fiber Volume, %	55.1	55.2	60 ± 2			x
Resin Content, % Wt.	29.0	29.4	Report		x	
Voids, %	1.0	0.0	2% Max		x	
Density, gm/cc	1.93	1.95	Report		x	

D. Material Disposition

Accept for All Usage ____________. Accept for Limited Use NASA Environmental Program - Task I

Reject ____________ and (a) Return to Vendor ____________ or (b) Scrap ____________.

Q.C. Eng. C.C. Murphy Date: 8/24/77

*Requalified 8/24/77.

*Fiber Wt. = 7.08 x SP. Gr. of fiber.

**No. specimens in Spec./No. specimens tested.

Table IV. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-484)

Appendix

Prepreg Lot No. 638	Date Received 4/3/75
Prepreg Type PR288/T300	Fiber Batch No. -----
Quantity 4,536 gms (10 lbs)	Resin Batch No. 371

	Vendor	M&PTL	Spec.	*Requal.	Accept	Reject
A. Fiber Data:						
Tensile Str., MPa (ksi), Avg.	---	---	Min.			
Tensile Mod., GPa (msi), Avg.	---	---				
Density, gm/cc, Avg.	1.74	1.74			x	
B. Prepreg Data:						
Fiber, gm/m² (ft²)*, Avg.	132.4 (12.3)	129 (12.0)	132 ± 4.3 (12.3 ± 0.4)		x	
Individual Specimens**	6/6	5/6	2/3		x	
Resin, gm/m² (ft²), Avg.	78.6 (7.3)	83 (7.7)	78.6 ± 4.3 (7.3 ± 0.4)		x	
Individual Specimens**	6/6	4/6	2/3		x	
Vols., % Wt., Avg.	0.1	0.0	2% Max.		x	
Individual Specimens**	6/6	6/6	2/3		x	
Gel Time, Mins. 383 K (230° F)	65	---	40 Min.		x	
Flow, % 383 K (230° F)	---	---	---			
Visual Discrepancies						
C. Laminate Data:						
Roll No.(s)						
Gel Time in Die, Mins.						
Thickness, cm (in.)		0.200 (0.079)	0.203 ± 0.005 (0.080 ± 0.002)		x	
Flex. Str. at RT., MPa (ksi)	1510 (219)	1620 (235)	1448 (210)	1565 (227)	x	
394 K (250° F, MPa (ksi)	1124 (163)	1193 (173)	1103 (160)	1165 (169)	x	
Flex. Mod. at RT, GPa (msi)	116.5 (16.9)	123 (17.8)	117 (17.0)	124 (18.0)	x	
394 K (250° F), GPa (msi)	112 (16.2)	116.5 (16.9)	110 (16.0)	120 (17.4)	x	
SBS Str. at RT, MPa (ksi)	106 (15.4)	98.6 (14.3)	96.5 (14.0)	99 (14.3)	x	
394 K (250° F), MPa (ksi)	79 (11.5)	62.7 (9.1)	62.1 (9.0)	63 (9.1)	x	
Fiber Volume, %	-----	59.1	60 ± 2		x	
Resin Content, % Wt.	-----	33.8	Report		x	
Voids, %	-----	0.0	2% Max		x	
Density, gm/cc	-----	1.55	Report		x	

D. Material Disposition

Accept for All Usage ____________. Accept for Limited Use NASA Environmental Program - Task I

Reject ________________ and (a) Return to Vendor ________________ or (b) Scrap ____________________.

Q.C. Eng. G.C. Murphy   Date: 8/24/77

*Requalified 8/24/77

*Fiber Wt. = 7.08 x SP. Gr. of fiber.

**No. specimens in Spec./No. specimens tested.

Table V. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-484)

Appendix B

Prepreg Lot No. 768 | Date Received 10/13/77

Prepreg Type SP313/S (1014) | Fiber Batch No. -----

Quantity 1,816 gms (4 lbs) | Resin Batch No. -----

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Tensile Str., MPa (ksi), Avg.					
Tensile Mod., GPa (msi), Avg.					
Density, gm/cc, Avg.	2.485				
B. Prepreg Data:					
Fiber, gm/m^2 (ft^2)*, Avg.	189.4 (17.6)	191.4 (17.786)	189.4 ± 6.4 (17.6 ± 0.6)	x	
Individual Specimens**	15/15	4/4	2/3	x	
Resin, gm/m^2 (ft^2), Avg.	77.5 (7.2)	67.1 (6.238)	78.5 ± 4.3 (7.3 ± 0.4)		x [c]
Individual Specimens**	13/15	0/4	2/3	x	
Vols., % Wt., Avg.	0.4	0.249	2% Max.	x	
Individual Specimens**		4/4	2/3	x	
Gel Time, Mins. 383 K (230° F)		57[a]	40 Min.	x	
Flow, % 383 K (230° F)					
Visual Discrepancies					
C. Laminate Data:					
Roll No.(s)					
Gel Time in Die, Mins.			0.203 ± 0.005		
Thickness, cm (in.)	0.206 (0.081)	0.200 (0.079)	(0.080 ± 0.002)	x	
Flex. Str. at RT., MPa (ksi)	1720 (249.5)	1792.7 (260)	1448 (210)	x	
394 K (250° F), MPa (ksi)	890 (129.1)[b]	1620 (235)	1172 (170)	x	
Flex. Mod. at RT, GPa (msi)	42.2 (7.13)	56.0 (8.12)	44.8 (6.5)	x	
394 K (250° F), GPa (msi)	44.7 (6.49)[b]	55.0 (7.97)	41.4 (6.0)	x	
SBS Str. at RT, MPa (ksi)	120 (17.4)	82.7 (12.0)	82.7 (12.0)	x	
394 K (250° F), MPa (ksi)	51 (7.4)[b]	66.2 (9.6)	51.7 (7.5)	x	
Fiber Volume, %	NR	58.68	60 ± 2	x	
Resin Content, % Wt.	NR	25.49	Report	x	
Voids, %	NR	1.87	2% Max	x	
Density, gm/cc	1.93	1.96	Report	x	

D. Material Disposition

Accept for All Usage ________. Accept for Limited Use NASA Environmental Program

Reject ________ and (a) Return to Vendor ________ or (b) Scrap ________.

Q.C. Eng. G.C. Murphy   Date: 11/30/77

*Fiber Wt. = 7.08 x SP. Gr. of fiber.

**No. specimens in Spec./No. specimens tested.

(a) Gelation time at 427 K (310° F) (not indicative of laminate).

(b) Tested at 450 K (350° F).

(c) Additional Resin film added to test panel.

Table VI. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-484)

Appendix

Prepreg Lot No. 743 — Date Received 10/5/77

Prepreg Type SP313/T300 — Fiber Batch No. -----

Quantity 1,816 gms (4 lbs) — Resin Batch No. -----

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Tensile Str., MPa (ksi), Avg.					
Tensile Mod., GPa (msi), Avg.					
Density, gm/cc, Avg.	1.7				
B. Prepreg Data:					
Fiber, gm/m^2 (ft^2)*, Avg.	128.1 (11.9)	137.2 (12.75)	132.4 ± 4.3 (12.3 ± 0.4)	x	
Individual Specimens**	3/3	2/4	2/3	x	
Resin, gm/m^2 (ft^2), Avg.	99 (9.2)	110 (10.23)	78.6 ± 4.3 (7.3 ± 0.4)[c]	x	
Individual Specimens**	0/3	0/4	2/3		x
Vols., % Wt., Avg.		0.365	2% Max.	x	
Individual Specimens**		4/4	2/3	x	
Gel Time, Mins. 383 K (230° F)		53[a]	40 Min.	x	
Flow, % 36 K (230° F)			---	x	
Visual Discrepancies					
C. Laminate Data:					
Roll No.(s)		3-3-1			
Gel Time in Die, Mins.			0.203 ± 0.005		
Thickness, cm (in.)		1218 (0.086)	(0.080 ± 0.002)		x
Flex. Str. at RT., MPa (ksi)	1624 (235.6)	1641 (238)	1448 (210)	x	
394 K (250° F), MPa (ksi)	1037 (150.4)[b]	1600 (232)	1103 (160)	x	
Flex. Mod. at RT, GPa (msi)	110 (16.0)	122 (17.7)	117 (17.0)	x	
394 K (250° F), GPa (msi)	106 (15.4)[b]	119 (17.3)	110 (16.0)	x	
SBS Str. at RT, MPa (ksi)	100.7 (14.6)	67.6 (9.8)	96.5 (14.0)		x
394 K (250° F), MPa (ksi)	55 (8.0)[b]	58.6 (8.5)	62.1 (9.0)		x
Fiber Volume, %	57.5	56.77	60 ± 2		x
Resin Content, % Wt.	---	35.32	Report	x	
Voids, %	---	0.66	2% Max	x	
Density, gm/cc	---	1.527	Report	x	

D. Material Disposition

Accept for All Usage ________. Accept for Limited Use NASA Environmental Program

Reject ________ and (a) Return to Vendor ________ or (b) Scrap ________.

Q.C. Eng. G.C. Murphy — Date: 10/31/77

*Fiber Wt. = 7.08 x SP. Gr. of fiber.

**No. specimens in Spec./No. specimens tested.

(a)Gelation time at 411 K (280° F) (not indicative of laminate).

(b)Tested at 450 K (350° F).

(c)Accepted on basis of A50TF180-S1 Specification 100 ± 11.8 (9.3 ± 1.1) gms/m^2 (ft^2)

Table VII. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-484)

Appendix B

Prepreg Lot No. C8-054 (Fiberite)	Date Received 11/1/77
Prepreg Type NR150A2/S (1014)	Fiber Batch No. Reichold Chemicals, Inc. - 63
Quantity 1,816 gms (4 lbs)	Resin Batch No. DuPont E14224-98

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Tensile Str., MPa (ksi), Avg.	3668 (532)				
Tensile Mod., GPa (msi), Avg.	86.9 (12.6)				
Density, gm/cc, Avg.	2.49				
B. Prepreg Data:					
Fiber, gm/m^2 (ft^2)*, Avg.	178 (16.5)	178 (16.55)	189 ± 6.4 (17.6 ± 0.6)		x
Individual Specimens**	0/3	1/3	2/3		x
Resin, gm/m^2 (ft^2), Avg.	109 (10.1)	112 (10.4)	78.5 ± 4.3 (7.3 ± 0.4)		x
Individual Specimens**	0/3	0/3	2/3		x
Vols., % Wt., Avg.	19.9[(a)]	18.9	2% Max.		x
Individual Specimens**	3	-----	2/3		x
Gel Time, Mins. 383 K (230° F)	1.7[(c)]	-----	40 Min.		
Flow, % 383 K (230° F)	33.5	-----	-----		
Visual Discrepancies					
C. Laminate Data:					
Roll No.(s)		01			
Gel Time in Die, Mins.			0.203 ± 0.005		
Thickness, cm (in.)	0.170 (0.067)	0.208 (0.082)	(0.080 ± 0.002)		
Flex. Str. at RT., MPa (ksi)	1434 (208)	1503 (218)	1448 (210)	x	
394 K (250° F), MPa (ksi)	-----	1296 (188)	1172 (170)	x	
Flex. Mod. at RT, GPa (msi)	50 (7.25)	53 (7.68)	44.8 (6.5)	x	
394 K (250° F), GPa (msi)	-----	49 (7.12)	41.4 (6.0)	x	
SBS Str. at RT, MPa (ksi)	49.0 (7.1)	66.2 (9.6)[(b)]	82.7 (12.0)		
394 K (250° F), MPa (ksi)		55 (8.0)	51.7 (7.5)	x	
Fiber Volume, %	56	54.16	60 ± 2		
Resin Content, % Wt.	26.2	30.34	Report	x	
Voids, %	11.6	5.62	2% Max		
Density, gm/cc	1.74	1.93	Report	x	
Cured Ply Thickness	0.0048				

D. Material Disposition

Accept for All Usage ________. Accept for Limited Use NASA Environmental Program

Reject ________ and (a) Return to Vendor ________ or (b) Scrap ________.

Q.C. Eng. G.C. Murphy Date: 11/30/77

*Fiber Wt. = 7.08 x SP. Gr. of fiber.
**No. specimens in Spec./No. specimens tested.
(a) 1/2 Hour at 589 K (600° F).
(b) Low shear values attributable to high void content.
(c) At 477 K (400° F).

Table VIII. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-484)

Appendix

Prepreg Lot No. C8-060 (Fiberite)	Date Received 11/1/77
Prepreg Type NR150A2/T300	Fiber Batch No. Union Carbide 366-2
Quantity 2,043 gms (4.5 lbs)	Resin Batch No. DuPont E14224-98

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Tensile Str., MPa (ksi), Avg.	2689 (390)	-----	Min.		
Tensile Mod., GPa (msi), Avg.	223 (32.3)	-----			
Density, gm/cc, Avg.	1.725	-----			
B. Prepreg Data:					
Fiber, gm/m^2 (ft^2)*, Avg.	148 (13.76)	150 (13.95)	132.4 ± 4.3 (12.3 ± 0.4)		x
Individual Specimens**	0/3	0/3	2/3		x
Resin, gm/m^2 (ft^2), Avg.	83 (7.3)	81 (7.5)	78.5 ± 4.3 (7.3 ± 0.4)	x	
Individual Specimens**	3/3	2/3	2/3	x	
Vols., % Wt., Avg.[(a)]	18.8	16.3	2% Max		x
Individual Specimens**		0/3	2/3		x
Gel Time, Mins. 383 K (230° F)	1.6[(b)]		40 Min.		x
Flow, % 383 K (230° F)			-----		
Visual Discrepancies					
C. Laminate Data:					
Roll No.(s)		01			
Gel Time in Die, Mins.			0.203 ± 0.005		
Thickness, cm (in.)[(c)]	0.200 (0.079)	0.226 (0.089)	(0.080 ± 0.002)		x
Flex. Str. at RT., MPa (ksi)	1496 (217)	1572 (228)	1448 (210)	x	
394 K (250° F), MPa (ksi)	-----	1289 (187)	1103 (160)	x	
Flex. Mod. at RT, GPa (msi)	111.2 (16.13)	124 (18.0)	117 (17.0)	x	
394 K (250° F), GPa (msi)		123 (17.9)	110 (16.0)	x	
SBS Str. at RT, MPa (ksi)	108 (15.7)	106 (15.4)	96.5 (14.0)	x	
394 K (250° F), MPa (ksi)	-----	82 (11.9)	62.1 (9.0)	x	
Fiber Volume, %	61	60.1	60 ± 2	x	
Resin Content, % Wt.	34.7	35.06	Report	x	
Voids, %	0	1.57	2% Max	x	
Density, gm/cc	1.62		Report	x	
Cured Ply Thickness	0.00562			x	

D. Material Disposition

Accept for All Usage_________. Accept for Limited Use NASA Environmental Program

Reject __________ and (a) Return to Vendor __________ or (b) Scrap __________.

Q.C. Eng. G.C. Murphy   Date: 11/30/77

*Fiber Wt. = 7.08 x SP. Gr. of fiber.
**No. specimens in Spec./No. specimens tested.
(a) Exposed to 589 K (600° F).
(b) At 477 K (400° F).
(c) 14 Plies.

- Maintain pressure and temperature for gel time plus two hours.

- Remove panel hot and postcure in oven for four hours at 408 K (275° F) followed by one hour at 450 K (350° F).

3.3.1.2 SP313 Composites

The SP313 test panels were molded and cured using the 3M Company recommended procedure.

- Insert layup in the die at 450 K (350° F).

- Apply contact pressure for three minutes.

- Increase molding pressure gradually to 550 KPa (80 psi) over three minute period.

- Hold for 30 minutes.

- Oven postcure for four hours at 450 K (350° F).

3.3.1.3 NR150A2 Composites

The initial processes used in the fabrication of the Material Quality Assurance test panels involved the following procedure.

- Spray steel mold with "Frekote" 33 mold release.

- Lay up prepreg plies in the matched die mold separated top and bottom with TeflonRelease Fabric (next to prepreg) followed by a sheet of "Celgard" 4510 microporous polypropylene film and then a sheet of dry glass fabric (181 Style).

- Premold at 477 K (400° F) for four to five hours at a constant 14 KPa (2 psi) applied pressure.

- Remove solid porous preform and layup in a Kapton[R] vacuum bag between two sheets of dry glass fabric. A solid metal caul plate is placed on top within the vacuum bag.

- Place in an oven overnight at 575 K (575° F) under vacuum.

- Preheat matched die mold to 616 K (650° F), insert preform, immediately apply at least 6895 KPa (1000 psi) and hold five minutes.

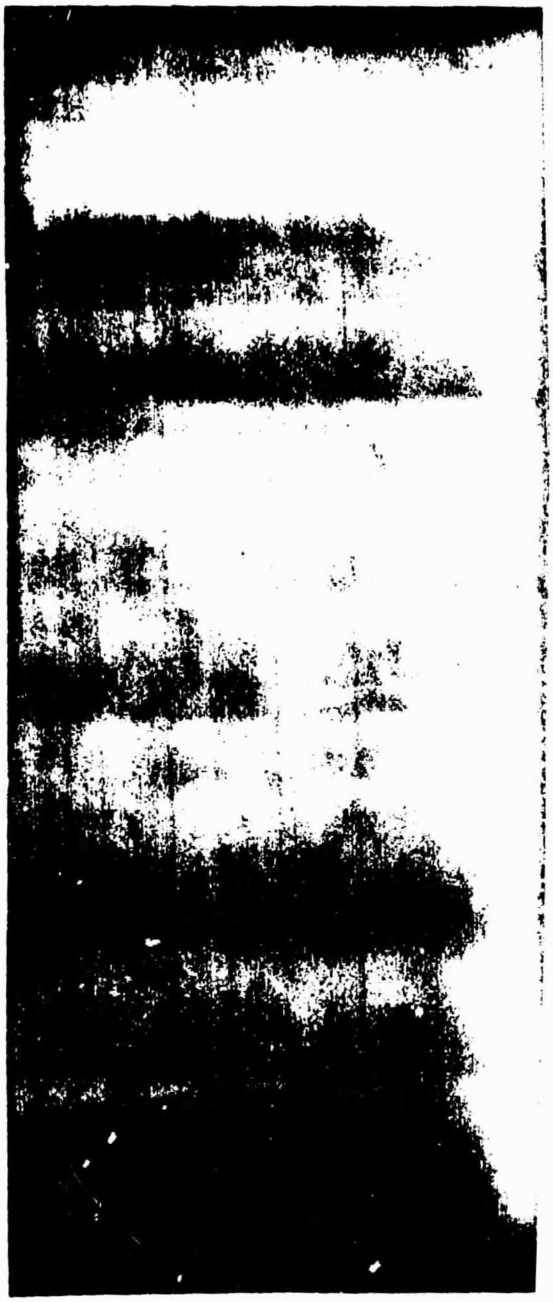
- Release pressure for thirty minutes.

- Reapply pressure for ten minutes and allow to cool under 1375 KPa (200 psi).

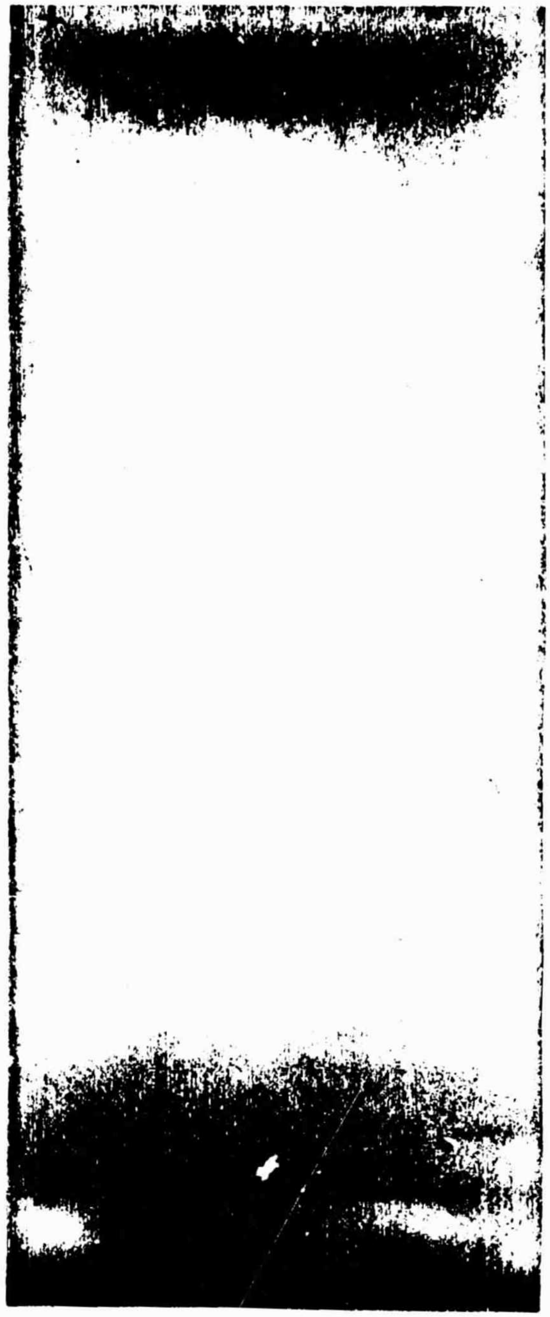
The mechanical properties generated from the Q.C. panel tests of the NR150A2/S(1014), Reference Table VIII indicated low short beam shear properties, which were mostly attributable to the high void content (5.6 percent) created by excess resin being expelled during the staging cycle. The process for molding the official test panels was modified after extensive studies to premolding the preform down to within 5 percent over the finished panel thickness during the 477 K (400° F) four-hour staging cycle. The procedure was instituted to retain sufficient matrix prior to final press molding. Ultrasonic C-scan inspection of the initial test panels indicated still unacceptable high void contents. Alternative staging/cure cycles were evaluated in an attempt to improve panel quality without success. Entrapment of solvent and by-products of the resin cure reaction were believed to be the cause of the voids, but high glass transition (T_g) temperatures in the 555 K- 577 K (540° F-580° F) range indicated that the solvent had basically been removed. Microscopic examination of sectioned panels revealed multiple small areas of interply micro-cracking and/or delamination was the major problem. In view of the thermoplastic nature of the NR150 material at temperatures above the T_g, the panels were subjected to secondary consolidation pressure/temperature cycles to determine if the microdelamination could be healed by plastic deformation and fusion of the resin matrix. Panel GB-1 was repressed at 630 K (675° F) and 20.7 MPa (3,000 psi) molding pressure in the mold tool and cooled to 394 K (250° F) under 1379 KPa (200 psi) pressure prior to removing from the die. Considerable improvement in the C-scan was noted. Figure 1 shows the initial C-scan gray scale of the panel in the as-molded condition and the gray scale after repressing at 630 K (675° F) and 20.7 MPa (3,000 psi).

The same panel was repressed for a second time at temperature/load conditions of 672 K (750° F) and 32.4 MPa (4,700 psi) and further improvement was noted (Figure 2). Figure 3 shows the magnified cross section (500X) of a typical panel before and after repressing indicating the successful plastic fusion of the microcracks by the developed process. The process has been christened PreDoT, <u>Pre</u>ssure <u>D</u>ensification <u>o</u>f <u>T</u>hermoplastics, and patent application is currently pending.

Mechanical properties of the NR150A2/T300 and NR150A2/S-glass were reevaluated to determine any changes resulting from the high PreDoT pressures applied to the test panels. Table IX shows the mechanical properties evaluated, comparing the initial QC test panel data with similar panels which were subjected to the PreDoT consolidation. Considerable improvement in the T300 unidirectional panel composite properties was achieved. Flexural strength increased from 1572 MPa (228 ksi) to 2006 MPa (291 ksi) at room temperature and 1289 MPa (187 ksi) to 1848 MPa (268 ksi) at 394 K (250° F). Short beam shear properties of the T300 also increased 10-14 percent. The S-glass/NR150A2 composite properties remained basically the same as the initial QC test data except for short beam shear, which increased 17-22 percent due to the reduced void content. Based upon the results of the material PreDoT properties, it was concluded that no significant damage had resulted to the glass or graphite fibers during the PreDoT processing and that the mechanical properties and laminate quality had considerably improved. All the official test panels were PreDoT conditioned prior to submitting to Cincinnati Testing Laboratories.



Panel GB-1
As Molded

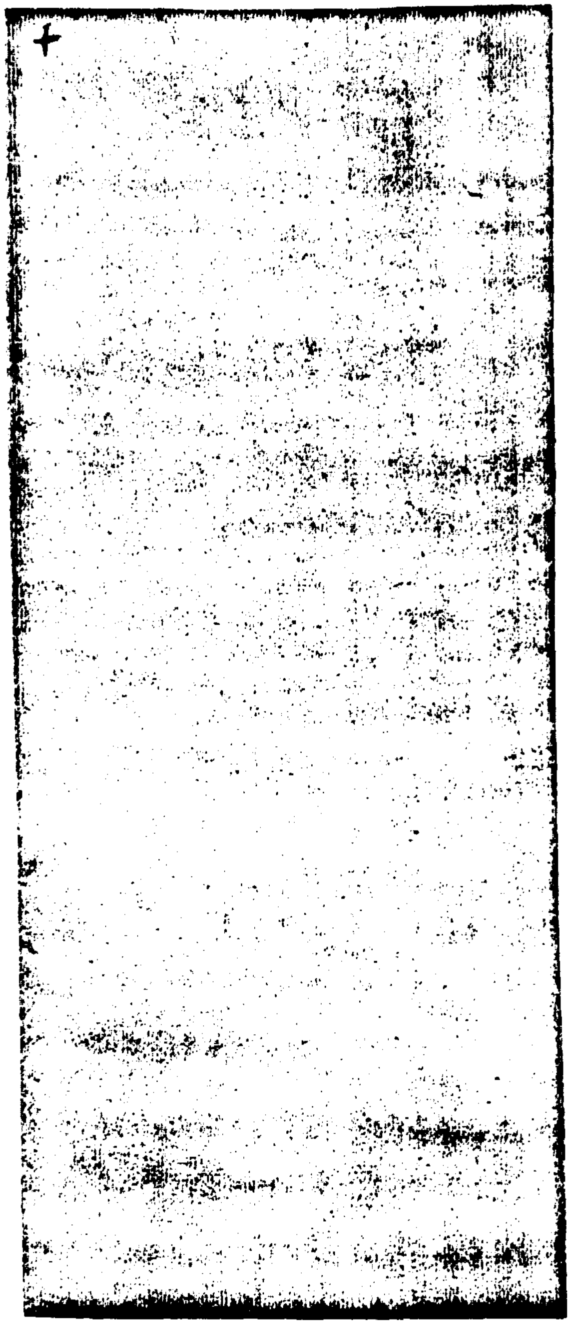


Panel GB-1
After "PreDoT" at
630 K (675° F and
20.68 MPa (3000 psi)

Ult·asonic C-Scan Gray Scale

Figure 1. Panel Quality Improvement by PreDoT Process (Pressure Densification of Thermoplastics).

ORIGINAL PAGE IS
OF POOR QUALITY



Panel GB-[illegible]
After "PreDoT" for a Second Time
at 672 K (750° F) and 33.41 MPa (4700 psi)

Ultrasonic C-Scan Gray Scale

Figure 2. Further Panel Quality Improvement By PreDoT Process (Pressure Densification of Thermoplastics).

Panel TB-3 - As Molded (500X)

Panel TB-3 After "PreDoT" Treatment (500X)

Figure 3. NR150A2/T300 Test Panel Quality Improved By "PreDoT" Process.

Table IX. NR150A2 Mechanical Properties Comparison After "PreDoT" Densification.

Material	Flexural Properties								Short Beam Shear Properties MPa (ksi)				Fiber Volume, %		Void Content, %	
	Flexural Strength MPa (ksi)				Flexural Modulus GPa (msi)											
	After PreDoT		QC Test Data		After PreDoT		QC Test Data		After PreDoT		QC Test Data					
	294 K (70° F)	394 K (250° F)	294 K (70° F)	394 K (250° F)	294 K (70° F)	394 K (250° F)	294 K (70° F)	394 K (250° F)	294 K (70° F)	394 K (250° F)	294 K (70° F)	394 K (250° F)	After PreDoT	QC Test Data	After PreDoT	QC Test Data
NR150A2/T300 (Panel TA-1 PreDoT)	2006 (291)	1848 (265)	1572 (228)	1289 (187)	145 (21.1)	145 (21.1)	124 (18.0)	123 (17.9)	117 (17)	94 (13.6)	106 (15.4)	82 (11.9)	62.29	60.1	1.15	1.57
NR150A2/S-Glass (Panel GA-6 PreDoT)	1462 (212)	1496 (217)	1503 (218)	1296 (188)	45.6 (6.62)	48 (6.99)	53 (7.7)	49 (7.1)	81 (11.8)	65 (9.4)	66 (9.6)	55 (8.0)	48.51	54	1.47	5.62

"PreDoT" Parameters: Temperature 672 K (750° F)
Pressure 31 MPa (4,500 psi)

3.3.2 Quality Assurance

All the molded test panels were subjected to ultrasonic C-scan inspection as a quality level determination prior to machining into test specimens. Laboratory analysis was conducted on samples of the molded panels to ascertain fiber volume, resin content, density and void contents. A tabulated list of the physical properties of the PR288 and SP313 test panels are shown in Table X and the NR150A2 are listed in Table XI.

3.4 SPECIMEN ENVIRONMENTAL CONDITIONING

The test panels were machined to produce the longitudinal and transverse flexural and short beam shear test specimens prior to moisture conditioning and testing in accordance with ASTM D790 flexural strength/modulus and ASTM D2344 short beam shear test methods.

3.4.1 Establishing Minimum Specimen Heating/Cooling Times

A study program was conducted using PR288/T300 and PR288/S-glass typical short beam shear (SBS) and flexural specimens to determine the minimum test temperature soak times required to attain the test condition. It was believed that the usual 15-30 minute soak times would partially expel the absorbed moisture at the elevated temperature test conditions, thus nullifying some of the moisture absorption effects.

Thermocouples were inserted into each specimen and monitored to record the time/temperature rise/fall rates. The specimens were not moisture conditioned for this investigation since it is not believed to be a significant variable in the heating/cooling of the specimens. The specimens were heated or cooled in an oven or freezer to the desired temperature rather than mounted in the actual test fixtures and equipment.

The times recorded to attain the test temperature are tabulated below:

Type Specimen	Test Temp. K (° F)	Exposure Temp. K (° F)	Recorded Time To Attain Test Temp
SBS	219 (-65)	216 (-70)	1 min 15 sec
	394 (250)	397 (255)	1 min 40 sec
Flex	219 (-65)	216 (-70)	2 min 30 sec
	394 (250)	397 (255)	2 min 20 sec

Graphical plots of the heating and cooling rates are illustrated in Figures 4 and 5.

Table X. Physical Properties of Molded PR288 and SP313 Test Panels.

Panel No. (Sample Ident. No.)	Material	Molded Properties		
		Density gm/cc	Fiber Vol. %	Void Content %
1086 (5021-1)	PR288/S	1.99	59.24	-0.02
1087 (5021-2)	PR288/S	1.96	56.14	-0.43
1084 (5022-1)	PR288/T300	1.54	57.4	-0.34
1089 (5022-2)	PR288/T300	1.55	56.4	-0.9
1885 (5038-3)	SP313/S	1.96	59.89	2.87
1886 (5038-4)	SP313/S	1.97	59.79	2.02
1883 (5038-1)	SP313/T300	1.52	55.37	0.68
1884 (5038-2)	SP313/T300	1.52	54.12	0.14

Fiber Orientation: $(0^\circ)_{16}$

Test Panel Size: 30.5 cm x 30.5 cm x 2.03 mm
(12 in. x 12 in. x 0.080 in.)

Table XI. Physical Properties of NR150A2 Test Panels.

Panel Number	Reinforcement Material	Thickness cm (in.)	Density gm/cc	Fiber Volume %	Void Content %
GA-1	1014 S-glass	0.198 (0.078)	2.000	---	---
GA-2	1014 S-glass	0.215 (0.085)	1.927	---	---
GA-3	1014 S-glass	0.221 (0.087)	1.897	---	---
GA-4	1014 S-glass	0.201 (0.079)	1.962	---	---
GA-5	1014 S-glass	0.218 (0.086)	1.964	---	---
GB-1	1014 S-glass	0.183 (0.072)	2.042	---	---
GB-2	1014 S-glass	0.178 (0.070)	2.048	63.35	2.33
TA-3	T300	0.196 (0.077)	1.654	---	---
TA-4	T300	0.203 (0.080)	1.636	---	---
TA-5	T300	0.196 (0.077)	1.654	68.78	0.83
TA-6	T300	0.198 (0.078)	1.615	---	---
TA-7	T300	0.193 (0.076)	1.640	---	---
TB-2	T300	0.203 (0.080)	1.615	---	---

Fiber Orientation: $(0^\circ)_{16}$

Test Panel Size: 17.8 cm x 7.6 cm x 2.03 mm
(7 in. x 3 in. x 0.080 in.)

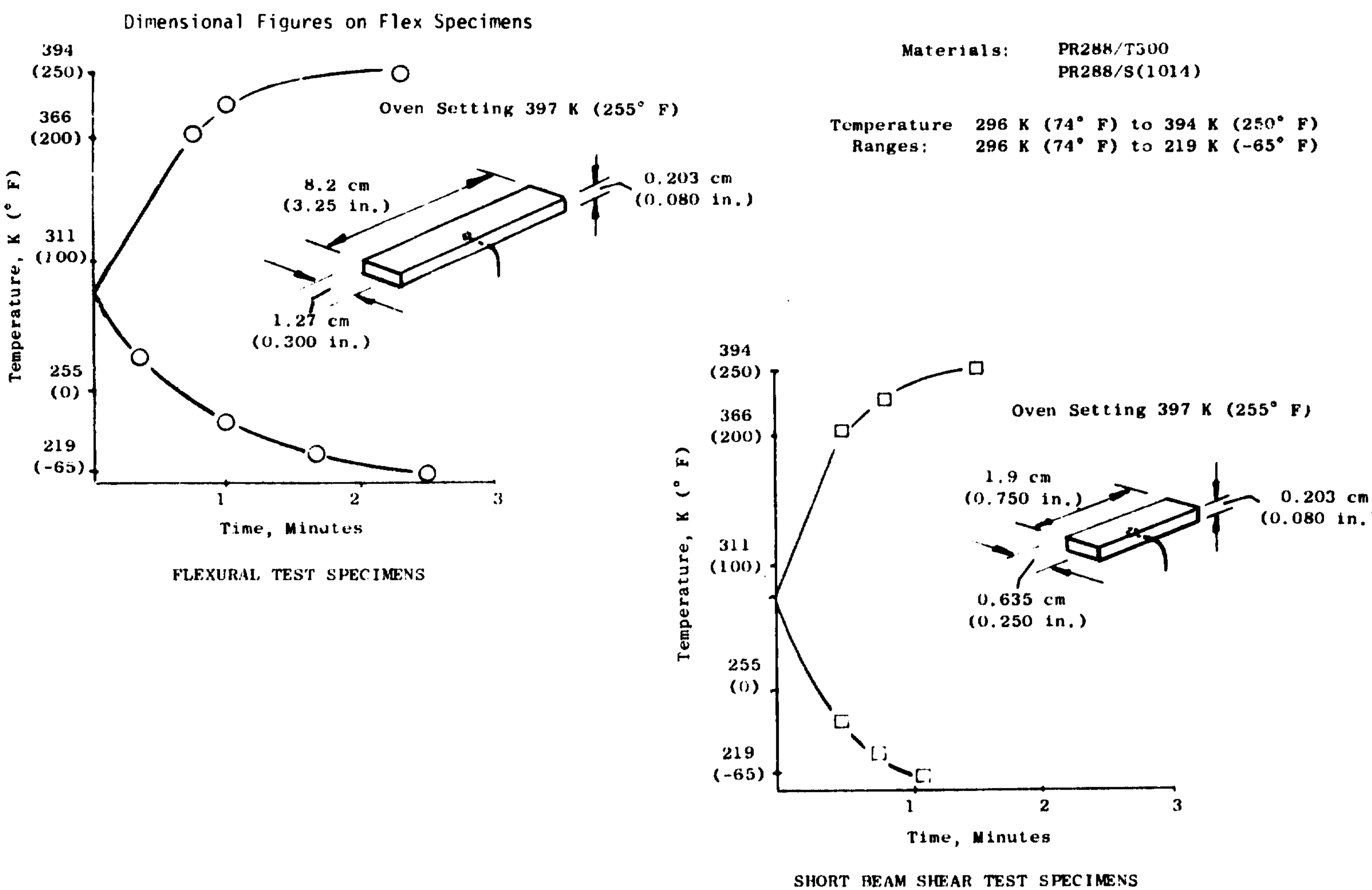


Figure 4. Flexural and Short Beam Shear Specimen Heating/Cooling Rates.

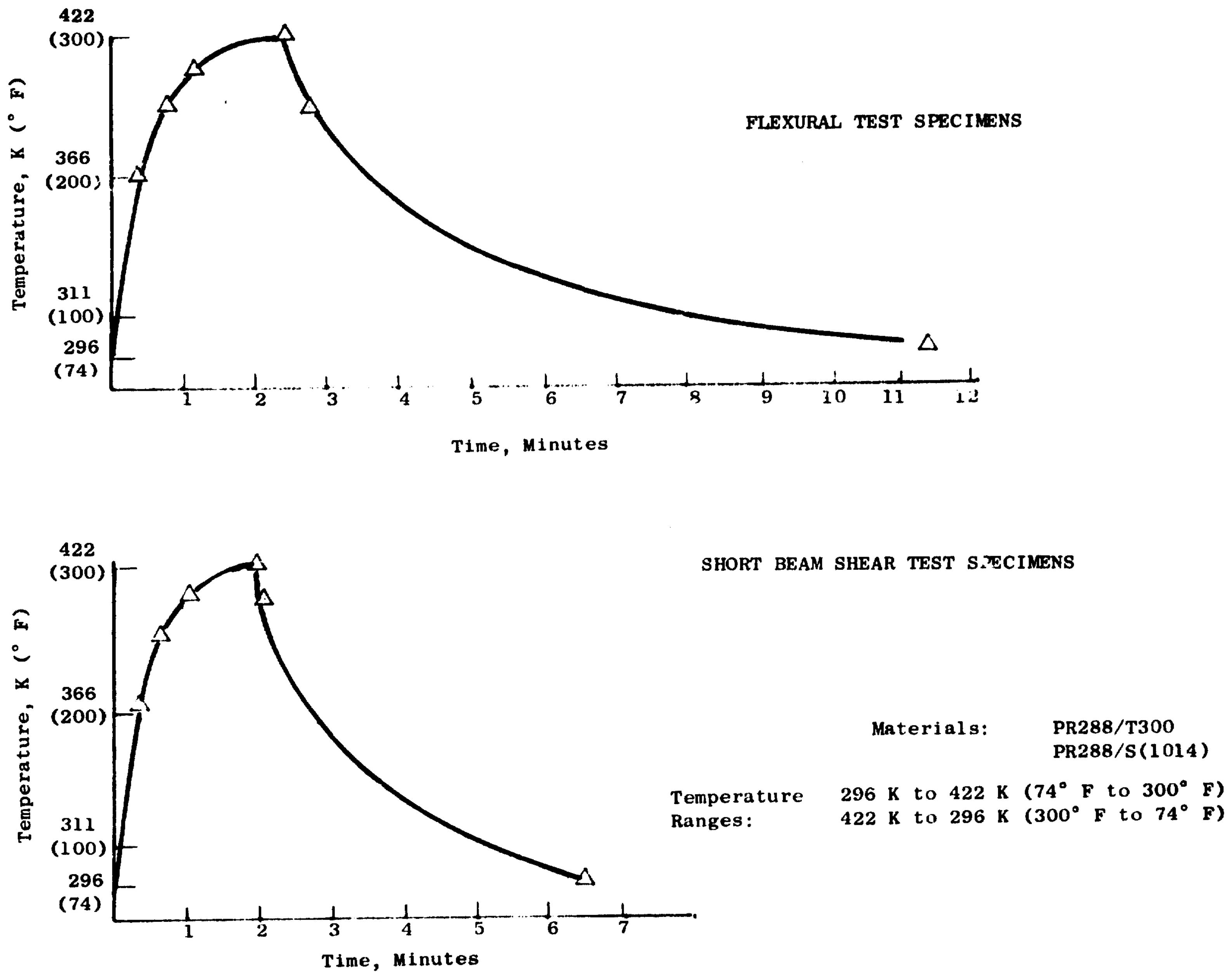


Figure 5. Specimen Heating/Cooling Rates.

3.4.2 Establishing "Dry" Specimen Conditioning Parameters

The nominally "dry" conditioned specimens tested during the program correspond to a moisture content acquired by prolonged exposure to 50 percent relative humidity and 294 K (70° F). General Electric has previously determined that 0.3 percent moisture weight gain over a period of three months is typical in an 0.203 cm (0.080 inch) thick unidirectional PR288/AS(80)/S(20) laminate (Figure 6). Due to different densities in the six composite systems being evaluated in the program, 0.3 percent weight of moisture is not valid for these systems. During the preliminary investigation, typical PR288/T300 and PR288/S-glass test specimens were conditioned at 355 K (180° F) and 97 percent relative humidity concurrently with control specimens of PR288/AS(80)/S(20). Time versus moisture content was recorded until the control specimens attained 0.3 percent weight moisture content. All the specimens were initially dried at 322 K (120° F) for sixteen hours to expel any surface moisture absorbed since the panels were fabricated, before moisture conditioning at 355 K (180° F)/97 percent relative humidity.

The total time required to achieve 0.3 percent weight gain in the various control specimens was:

Specimen Type	Conditioning Time 355 K (180° F)/97% RH
Short Beam Shear	4.0 Hours
Flexural Specimens	70.5 Hours

The weight percentage gained for each specimen is tabulated in Table XII.

3.4.3 Moisture Changes During Specimen Heating/Cooling

Nominally "dry" specimens were placed in a cryogenic chamber set at 216 K (-70° F) to bring specimens to the 219 K (-65° F) test temperature. Specimens were weighed immediately after reaching 219 K (-65° F) and a significant increase in weight due to increased moisture content was noted in all instances. The actual weight increase and percentage of increase are shown in Item 3 on Table XIII. Specimens were maintained at 219 K (-65° F) an additional 30 minutes after reaching 219 K (-65° F) and reweighed. A further significant weight increase was noted at that time, as shown in Item 4 of Table XIII.

The additional weight was identified as frost formed from surface condensation during the rapid cooling cycle. When specimens were removed from the 216 K (-70° F) environment and brought to 296 K (74° F), the surface moisture was removed by blotting.

The specimens were then heated from 296 K (74° F) to 394 K (250° F) in an oven set at 397 K (255° F) and weighed when the 294 K (250° F) test temperature was attained. Item 5 of Table XIII shows that some specimens weighed less than the weight shown for the fully dry condition in Item 1 of the table,

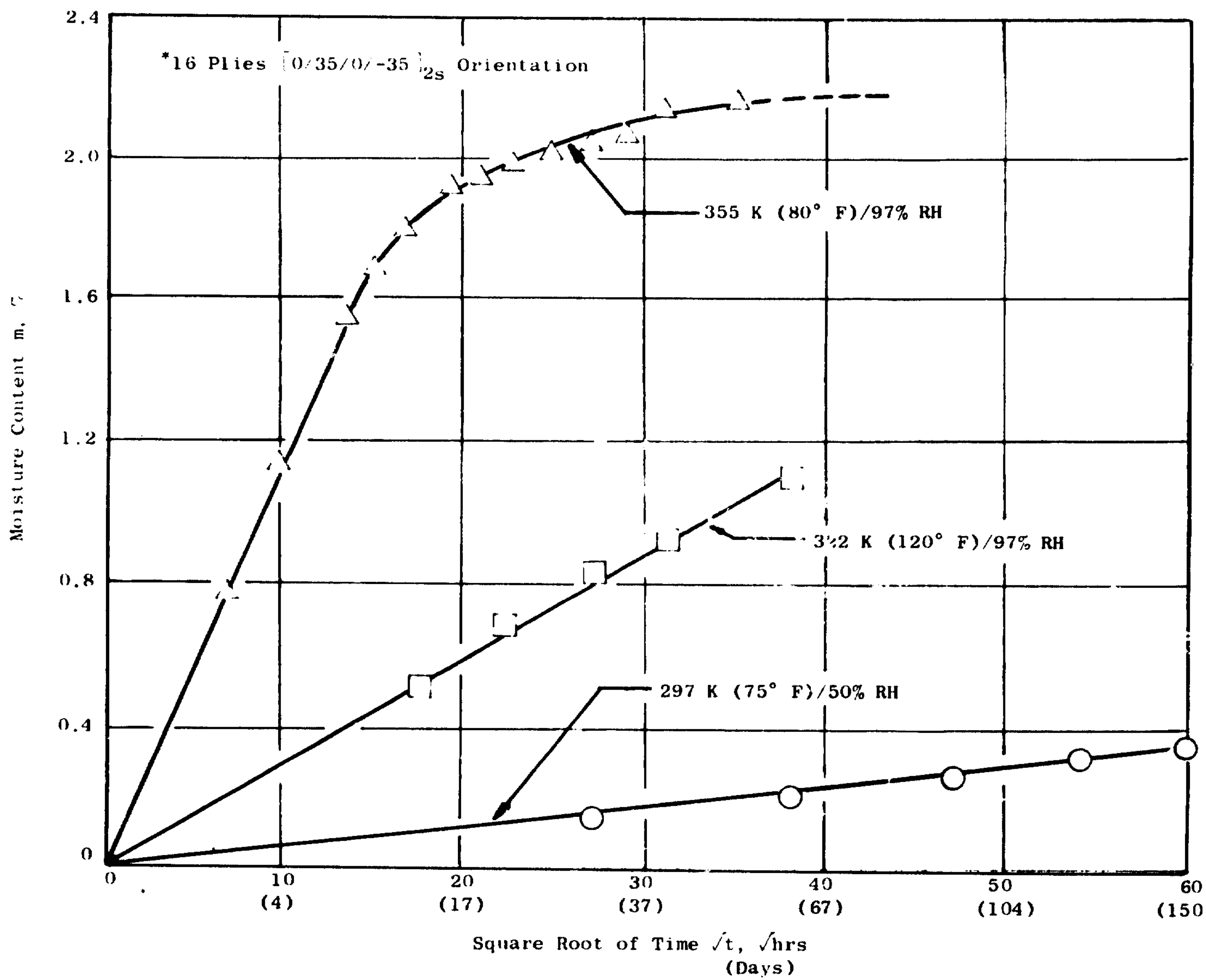


Figure 6. Effect of Exposure Conditions on the Moisture Content of PR288/AS(80)/S-Glass(20) Composites.

Table XII. "Dry" Conditioning of Test Specimens Moisture Weight Gain Percentages.

Material/ Specimen Design	Predried(1) Weight (gm)	"Dry"(2) Weight (gm)	Percentage Weight Gain After Conditioning
*AS/S #1 SBS (0°)	0.4169	0.4182	0.31
*AS/S #2 SBS (0°)	0.4126	0.4136	0.24
S-glass SBS (90°)	0.5263	0.5274	0.21
T300 SBS (90°)	0.4041	0.4051	0.25
S-glass Flex (0°)	3.7600	3.7698	0.26
T300 Flex (0°)	3.1122	3.1216	0.3

(1) Predried for 16 hours at 322 K (120° F)

(2) After conditioning at 355 K (180° F)/97% RH SBS 4 hours and Flex 70.5 hours

*Control Specimens.

Table XIII. Moisture Change in Nominally "Dry" Test Specimens Due to Temperature Cycling.

Type Specimen and Reinforcement / Specimen Conditioning Temperature, and Cycling Sequence	Control SBS 0° AS/S Wt, gm % Change	Control SBS 0° AS/S Wt, gm % Change	SBS 90° S-glass Wt, gm % Change	SBS 90° T300 Wt, gm % Change	Flex 0° S-glass Wt, gm % Change	Flex 90° T300 Wt, gm % Change	Avg
1. Fully Dry(1) Baseline Weight	0.4169	0.4126	0.5263	0.4041	3.7600	3.1122	
2. Conditioned Nominally "Dry"(2)	0.4182 +0.31	0.4138 +0.24	0.5274 +0.21	0.4051 +0.25	3.7698 +0.26	3.1216 0.30	0.27
3. 296 K to 219 K at 219 K(3) (74° F to -65° F at -65° F)	0.4188 +0.46	0.4148 +0.53	0.5286 +0.44	0.4064 +0.57	3.7737 +0.37	3.1309 +0.60	
4. Wt. After 1/2 Hr at 219 K (-65° F)	0.4195 +0.62	0.4158 +0.78	0.5299 +0.68	0.4075 +0.84	3.7881 +0.75	3.1411 +0.93	
5. 296 K to 394 K at 394 K (74° F to 250° F at 250° F)	0.4172 +0.07	0.4125 -0.02	0.5258 -0.096	0.4031 -0.25	3.7618 +0.048	3.1150 +0.09	
6. Wt. After 1/2 Hr at 394 K (250° F)	0.4172 +0.07	0.4123 -0.07	0.5259 -0.03	0.4032 -0.22	3.7601 0.00	3.1126 +0.013	
7. Loss From Nominally "Dry"(4) After 1/2 Hr at 394 K (250° F)	0.0010 0.24	0.0013 0.31	0.0015 0.28	0.0019 0.47	0.0097 0.26	0.0090 0.29	0.31

1. Fully dry specimens were attained by exposing molded specimens at 322 K (120° F) for 16 hours. Moisture loss or gain was computed from the established dry weight.
2. Nominally "Dry" specimens were attained by conditioning specimens at 97% RH and 355 K (180° F).
3. Specimens weighed immediately after removal from 219 K (-65° F) conditioning chamber. Weight increase due to moisture condensation.
4. Percentage of loss in Item 7 is based on nominally "dry" condition in Item 2.

indicating that the 16 hours at 322 K (120° F) was not sufficient to totally remove the original moisture. Specimens were maintained at 394 K (250° F) for a total time of 30 minutes and reweighed with no significant weight change, as shown in Item 6 of the table. Item 7 on the table shows that the 394 K (250° F) temperature caused an average loss of 0.31 percent moisture from the nominally dry condition listed in Item 1 of Table XIII.

The specimens were further conditioned at 355 K (180° F)/97% RH to attain a higher moisture level (semi-wet) to evaluate moisture losses during heat cycling at these higher saturation levels. Semi-wet specimens were weighed to determine the weight percentage of moisture content after being removed from the humidity chamber. After weighing, the specimens were heated from 296 K (74° F) to 394 K (250° F) in an oven set at 397 K (255° F) and reweighed. The weight loss and percentage of weight change from the semi-wet condition in Item 2 of Table XIV is shown in Item 4 of the table and averages 0.20 percent for all specimens combined.

Specimens were further reconditioned to a similar semi-wet condition after exposure at 394 K (250° F), and Item 5, Table XIV shows the weight percentage moisture level after further reconditioning. The specimens were then subjected to the 422 K (300° F) [simulated wet spike condition] and reweighed at 422 K (300° F) to determine the moisture content compared to the fully dry condition shown in Item 1, Table XIV. After cooling from 422 K (300° F) to 296K (74° F), it was noted that the specimens gained weight. The weight increase in the cooling cycle indicated by the difference in Items 6 and 7, is tabulated in Item 8, Table XIV. Reabsorption of moisture in the cooling cycle is an average of 0.1 percent for all specimens combined.

3.4.4 Environmental Conditioning Procedure

Based upon the foregoing studies, the following procedures were established for conditioning and testing the specimens in accordance with the test matrix shown in Table XV.

- "Dry" Conditioning/Testing
  - Dry all specimens for 16 hours at 394 K (250° F).
  - Immediately weigh specimen (datum weight).
  - Condition specimens at 355 K (180° F)/97% RH until control specimen [PR288/AS(80)/S(20)] achieves 0.5% moisture weight gain.
- Room Temperature Tests
  - Allow specimens to cool to room temperature.
  - Reweigh specimen.

Table XIV. Moisture Change in Semi-Wet Specimens Due to Temperature Cycling.

Type Specimen and Reinforcement	SBS 0° S-glass	SBS 90° S-glass	SBS 0° T300	SBS 90° T300	Flex 0° S-glass	Flex 90° S-glass	Flex 0° T300	Flex 90° T300	
Specimen Conditioning Temperature and Cycling Sequence	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Wt, gm % Change	Avg.
1. Fully Dry(1) Baseline Weight	0.4859	0.4698	0.9769	0.4285	4.1409	4.1636	3.3800	3.3454	
2. Conditioned Semi-Wet(2)	0.4939 +1.65	0.4786 +1.87	0.4363 +1.82	0.3849 +2.12	4.2059 +1.57	4.2317 +1.64	3.4407 +1.80	3.4096 +1.72	
3. 296 K to 394 K at 394 K (74° F to 250° F at 250° F)	0.4929 +1.44	0.4774 1.62	0.3834 +1.72	0.4[illegible]50 +1.75	4.1997 +1.42	4.2243 +1.46	3.4337 +1.49	3.4028 +1.72	
4. Wt. Loss From 296 K to 394 K (74° F to 250° F) Wt. % Loss	0.0010 0.21	0.0008 0.25	0.0015 0.40	0.0003 0.07	0.0062 0.15	0.0074 0.18	0.0070 0.21	0.0068 0.20	0.20
5. Reconditioned to Semi-Wet(3)	0.4965 +2.18	0.4815 +2.49	0.3854 +2.26	0.4400 +2.68	4.2115 +1.70	4.2362 +1.74	3.4465 +1.97	3.4143 +2.06	
6. 296 K to 422 K at 422 K (74° F to 300° F at 300° F)	0.4846 +1.79	0.4776 +1.66	0.3841 +1.9[illegible]	0.4368 +1.94	4.2034 +1.51	4.2269 +1.52	3.4378 +1.71	3.4056 +1.80	
7. 422 K to 296 K at 296 K (300° F to 74° F at 74° F)	0.4955 +1.98	0.4783 +1.81	0.3847 +2.07	0.4372 +2.03	4.2054 +1.56	4.2290 +1.57	3.4399 +1.77	3.4080 +1.87	
8. Reabsorption(4) in Cooling - % Gain	0.0009 0.19	0.0007 0.15	0.0006 0.16	0.0004 0.09	0.0020 0.05	0.0021 0.05	0.0021 0.06	0.0024 0.07	0.10

1. Fully dry specimens were attained by exposing molded specimens at 322 K (120° F) for 16 hours. Moisture loss or gain was computed from the established dry weight.
2. Semi-wet specimens were attained by conditioning specimens at 97% RH and 355 K (180° F).
3. Specimens were reconditioned to semi-wet condition prior to 422 K (300° F) wet spike due to moisture lost in heating to 394 K (250° F).
4. Moisture was reabsorbed from atmosphere while cooling to the 296 K (74° F) after 422 K (300° F) wet spike.

Table XV. Mechanical Properties Evaluation Test Matrix.

Test Specimens		Test Conditions																				
		219 K (-65° F)			294 K (70° F)									394 K (250° F)								
Materials	Specimen Type and Layup	Dry			Dry			Wet			Wet Spike			Dry			Wet			Wet Spike		
		M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
T300/M_1, M_2, M_3	SBS/0°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	SBS/90°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Flex/0°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Flex/90°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
S-glass/M_1, M_2, M_3	SBS/0°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	SBS/90°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Flex/0°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Flex/90°	3			3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

<u>Matrix Materials</u>

M_1 - PR288 (Epoxy)
M_2 - SP313 (Epoxy)
M_3 - NR150A2 (Polyimide)

<u>Fibers</u>

T300 - T300 Graphite
S-glass - S1014

- Allow to stand at room temperature or force dry at 339 K (150° F) until the moisture level in the control specimen drops to 0.3%.

- Record weight percentage.

- Test Specimen.

- Immediately reweigh specimen.

- 394 K (250° F) Temperature Tests

  - Allow specimen to cool to room temperature.

  - Weigh specimen.

  - Soak at test temperature in fixture for 15 minutes - SBS and Flex specimens.

  - Test specimen.

  - Immediately reweigh specimen.

- 219 K (-65° F) Temperature Tests

  - Allow specimen to cool to room temperature.

  - Weigh specimen.

  - Soak at test temperature in fixture for 15 minutes - SBS and Flex specimens.

  - Test specimen.

  - Immediately reweigh specimen (blot away condensation on specimen).

3.4.5 Moisture Absorption Rates

Control specimens of each material and specimen design were monitored during conditioning in the humidity cabinet to determine "full moisture saturation." Figures 7 through 10 show the moisture weight gain percentage against time plots for each specimen/material combination. The reduced moisture absorption of the more "moisture resistant" SP313 system is evident from the curves when compared to the PR288 composites. The exceptional "moisture resistance" of the NR150 resin compared to the epoxy systems can also be seen. It can also be noted that the moisture is absorbed at a faster rate in the transverse (90°) fiber predominant NR150A2 specimens indicating wicking at the matrix/fiber interface and the need for more compatible fiber finishes/sizes to achieve more intimate adhesion.

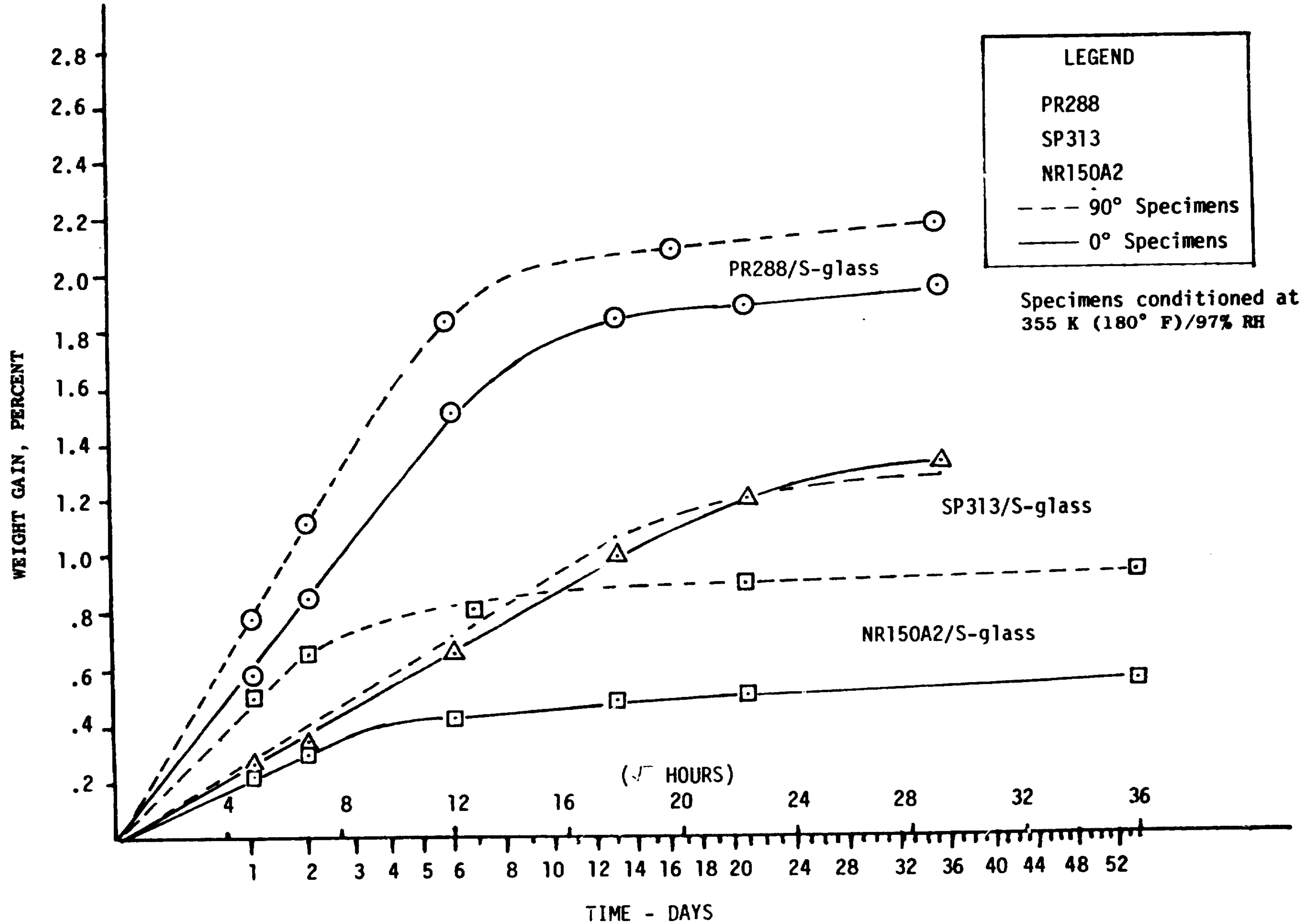


Figure 7. Moisture Absorption Rate S-Glass Flexural Specimens.

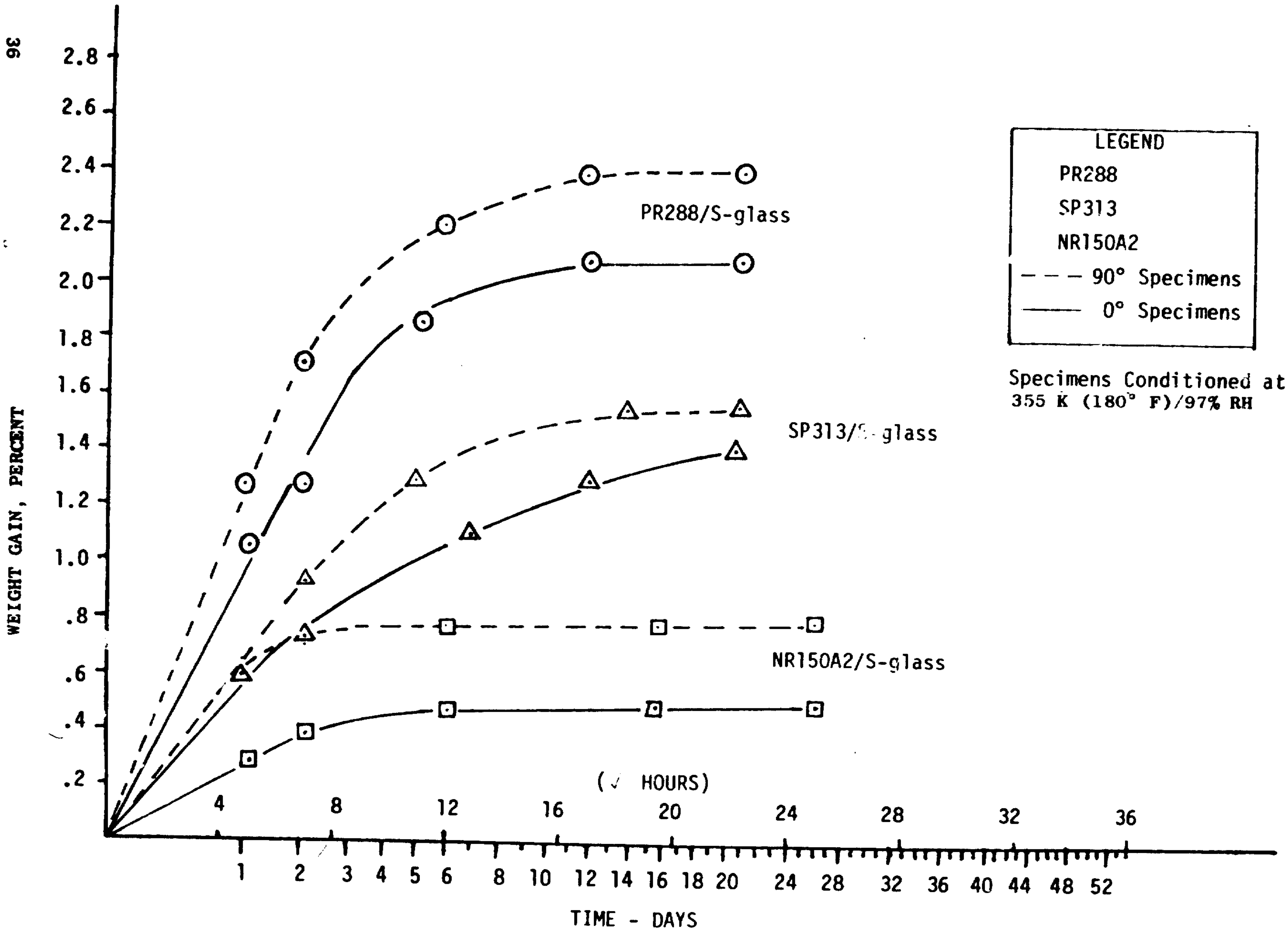


Figure 8. Moisture Absorption Rate S-Glass Short Beam Shear Specimens.

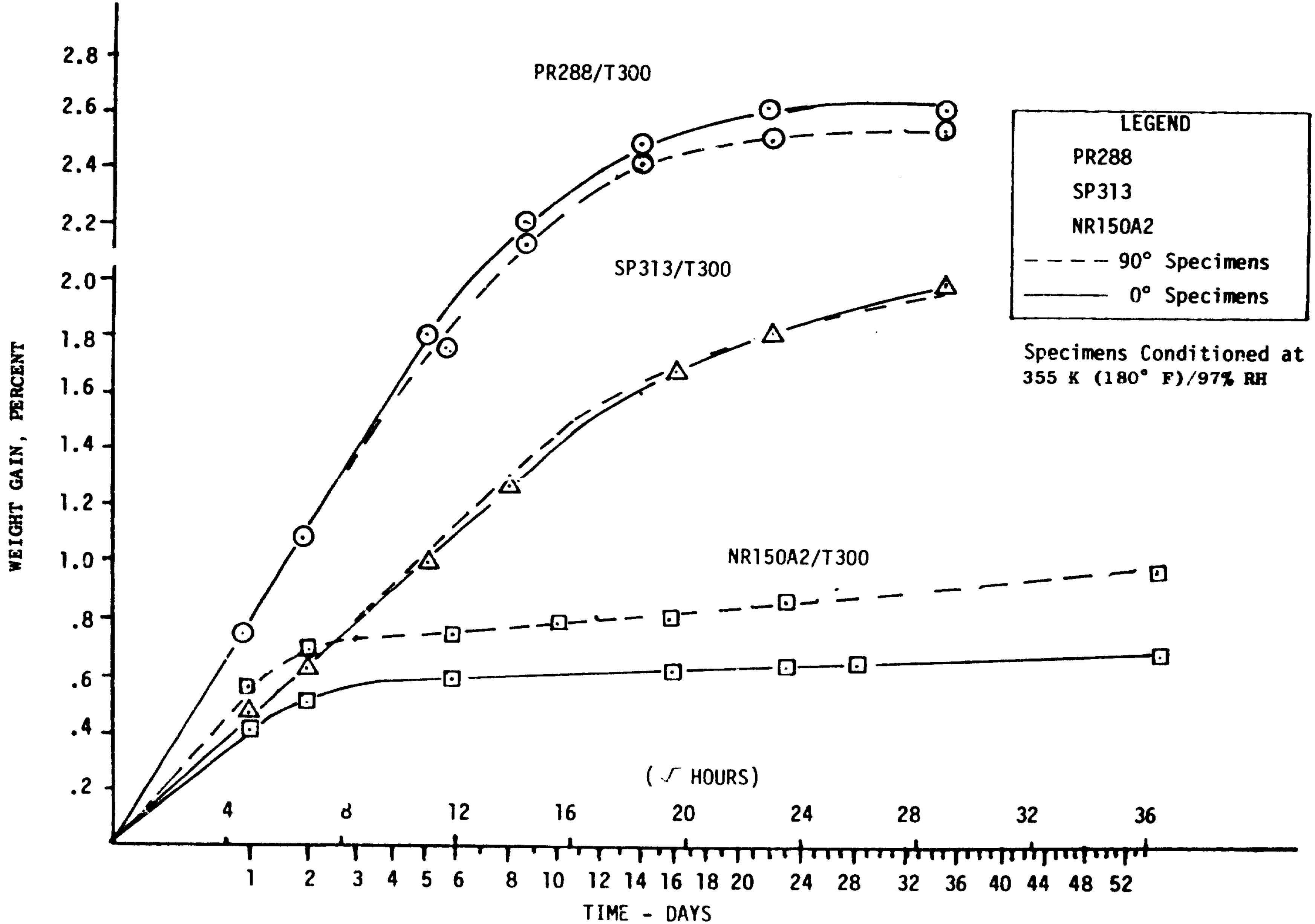


Figure 9. Moisture Absorption Rate T300 Flexural Specimens.

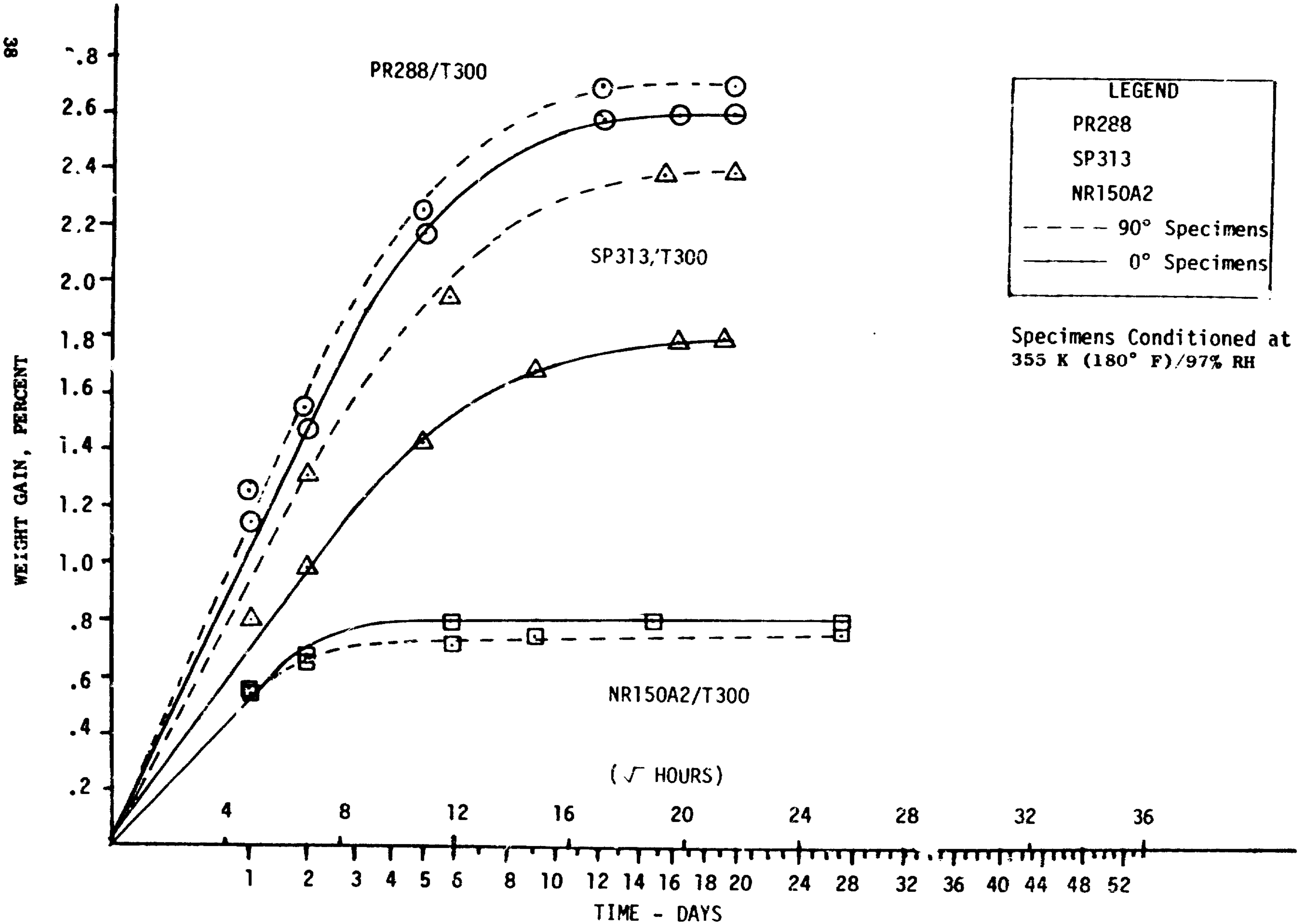


Figure 10. Moisture Absorption Rate T30C Short Beam Shear Specimens.

3.5 MECHANICAL PROPERTIES TESTING

3.5.1 Flexural Strength Tests

Flexural strength tests on the "dry," fully saturated and wet spike specimens with 0° and 90° fiber orientation were conducted in accordance with ASTMD790 using the three point loading method for the 0° orientation and the four point loading procedure for the 90° specimens.

3.5.2 Short Beam Shear Tests (SBS)

Short beam shear strength tests on the 0° and 90° orientation specimens were conducted in accordance with ASTMD2344.

The span (L) to depth (D) ratio test parameters for the 90° (transverse) short beam shear test specimens was evaluated in an attempt to produce a true shear failure in the specimens. Typical SBS specimens were manufactured using PR288/T300 and PR288/S-glass materials and tested at room temperature with L/D ratios of 5:1, 4:1, 3:1, and 2:1. All the specimens fractured cleanly, visually indicating a tensile type matrix failure mode opposite the point of center load application, there was no positive indication of any shear type failure at the median section of the specimen. Figure 11 depicts the span/depth ratio effect on SBS properties. Since the properties varied proportionally with the L/D ratio, a 2:1 relationship was chosen for the 90° (transverse) specimens tests to yield maximum initial values and thereby be able to determine more accurately the effects of moisture absorption. A 5:1 L/D ratio was selected for all the 0° (longitudinal) SBS specimen tests.

3.5.3 Results of Mechanical Properties Testing

3.5.3.1 "Dry" Conditioned Tests

All the machined specimens were conditioned at 394 K (250° F) for 16 hours to remove any moisture which might have been absorbed since the panels were molded and the datum weights recorded. The specimens were then conditioned at 355 K (180° F)/97% RH in an environmental chamber until control specimens of PR288/AS(80)/S(20) material had achieved 0.5 percent moisture weight gain. The 0.5 percent weight gain parameter was established based upon the previous work conducted on PR288/AS(80)/S(20) where it had been determined that 0.3% moisture was absorbed over a period of three months at ambient 50 percent RH and 294 K (70° F) conditions and therefore, fulfilled the nominally "dry" requirement. An additional 0.2% was allowed for moisture loss from specimen edges during elevated temperature tests as determined from the preliminary studies which were reported in Paragraph 3.4.2. The room temperature and the 294 K (-65° F) test specimens were partially dried to remove the excess 0.2 percent moisture from the external surfaces and achieve a more uniform moisture gradient across each specimen.

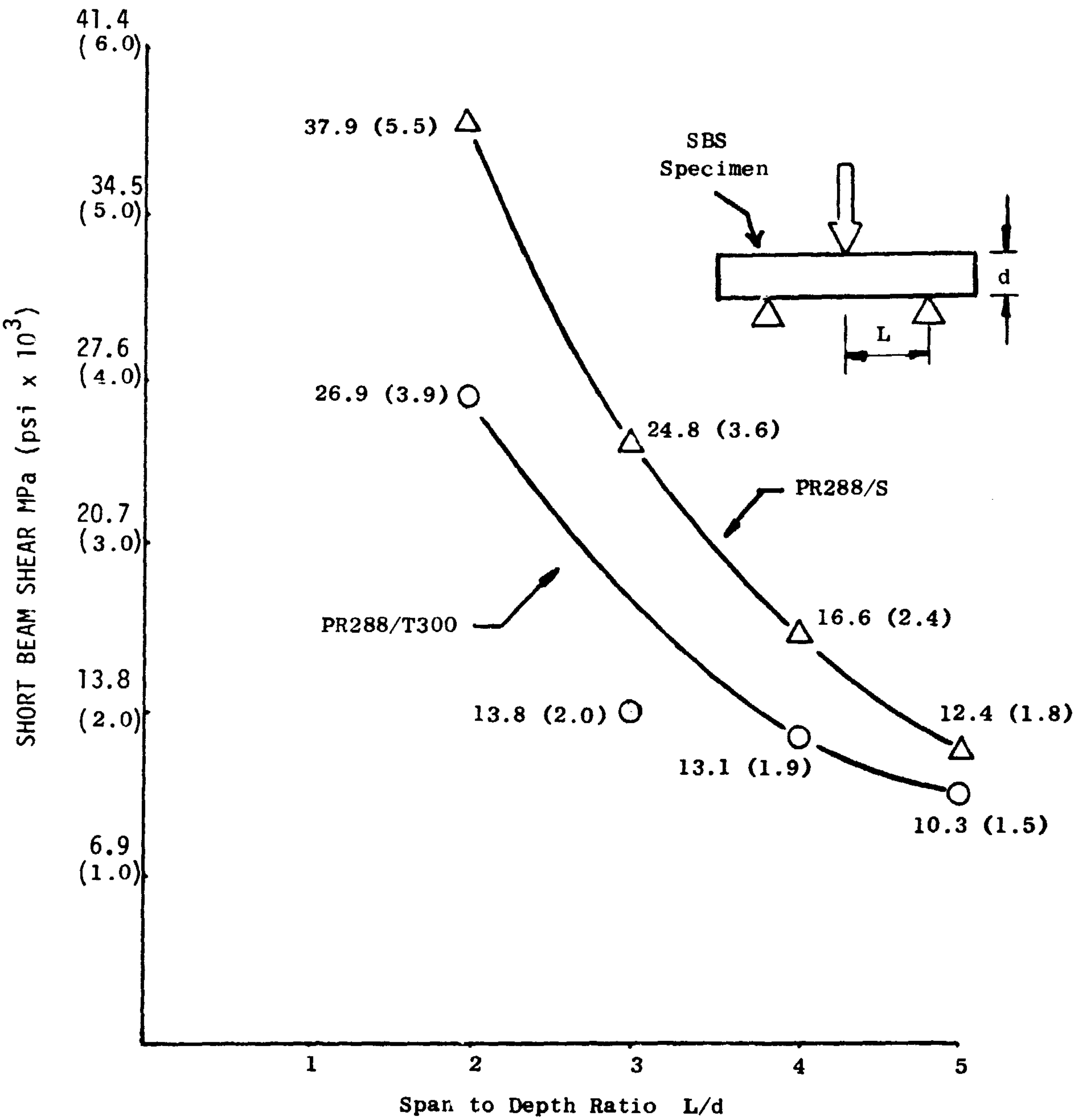


Figure 11. Span/Depth Ratio Effect on Short Beam Shear Stress at Tensile Failure.

- 90° transverse short beam shear specimens.

  Allowed to stand at room temperature until PR288/AS/S control specimen dropped to a 0.3 percent weight gain.

- 0° unidirectional short beam shear specimens.

  Subjected to 20 hours at 339 K (150° F) after conditioning until control specimen reach 0.3 percent weight gain.

- 90° transverse flexural specimens.

  Dried for 26 hours at 339 K (150° F) until control specimen reached 0.3 percent weight gain.

- 0° unidirectional flexural specimens.

  Dried for 16 hours at 339 K (150° F) and further 3.5 hours at 322 K (120° F) until control specimen achieved 0.3 percent weight gain.

The specimen conditioning times established for each specimen design to achieve the 0.5% moisture weight gain are tabulated in Table XVI.

Table XVI. Specimen Moisture Conditioning Times.

Specimen Design	Conditioning Time at 355 K (180° F)/97% RH
Flexural 0°	19.5 Hours
Flexural 90°	19.5 Hours
Short Beam Shear 0°	23.5 Hours
Short Beam Shear 90°	6.0 Hours

The weight of each individual specimen was recorded: (1) after drying, (2) after preconditioning to 0.5 percent weight at 355 K (180° F)/97% RH, (3) after drying to achieve 0.3 percent weight gain in PR288/AS/S control specimens and (4) immediately after testing. The specimens were immediately tested upon attaining the desired moisture content in the control specimens.

The flexural and short beam shear test results of the 'dry' conditioned specimens were compared against the initial room temperature and 394 K (250° F) Quality Control data. It was basically concluded that the 'dry' conditioning (~0.3 percent moisture did not affect the material properties and therefore, the 'dry' properties would be used as the basis for comparison of properties tested at all other test temperatures and specimen conditions. The 'dry' strength data at 219 K (-65° F), 294 K (70° F) and 394 K (250° F) shown on Tables XVII through XXXVI is therefore used as a baseline for calculating percentage strength retention against 'wet' or 'wet spike' properties. PR288/T300 and

Table XVII. Flexural Strength Properties, "Dry 219 K (-65° F) Temperature Test Data - Unidirectional (0°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry 294 K (70° F)	Dry 219 K (-65° F)	Dry 294 K (70° F)	Dry 219 K (-65° F)	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300		1520 (220.5)		119 (17.24)			0.26	0.36
		1654 (239.9)		118 (17.16)			0.27	0.35
	1633	1577 (228.8)	119	115 (16.68)			0.28	0.34
	(236.8)	1543 (223.7)	(17.25)	117 (17.03)	97	99	0.26	0.35
PR288/S-Glass		1723 (249.9)		55.2 (8.00)			0.20	0.32
		1723 (249.9)		55.2 (7.96)			0.21	0.21
	1520	1735 ([illegible]1.7)	53.4	55.2 (7.95)			0.21	0.33
	(220.5)	1727 (250.5)	(7.75)	55.2 (7.97)	113	102	0.21	0.29

Table XVIII. Flexural Strength Properties, "Dry 219 K (-65° F) Temperature Test Data - Transverse (90°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry 294 K (70° F)	Dry 219 K (-65° F)	Dry 294 K (70° F)	Dry 219 K (-65° F)	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300		60.6 (8.8)		10.55 (1.53)			0.29	0.42
		60.8 (8.8)		10.69 (1.55)			0.29	0.35
	36.2	56.0 (8.1)	9.03	11.72 (1.70)			0.30	0.37
	(5.26)	59.1 (8.6)	(1.31)	10.96 (1.59)	163	121	0.29	0.38
PR288/S-Glass		104.1 (15.1)		17.93 (2.60)			0.27	0.39
		95.2 (13.8)		17.69 (2.56)			0.25	0.37
	68	109.1 (15.8)	14.5	18.00 (2.61)			0.26	0.39
	(9.86)	102.8 (14.9)	(2.11)	17.86 (2.59)	151	123	0.26	0.38

Table XIX. Short Beam Shear Properties, "Dry" 219 K (-65° F) Temperature Test Data - Unidirectional (0°).

Material	Dry Strength 294 K (70° F) MPa (ksi)	Dry Strength 219 K (-65° F) GPa (msi)	Strength Retention, Percent	Moisture, Percent	
				Pretest	Posttest
PR288/T300		138 (20.1)		0.18	0.35
		138 (20.0)		0.15	0.22
	101	128 (18.5)	133	0.15	0.25
	(14.7)	135 (19.5)		0.16	0.27
PR288/S-Glass		146 (21.2)		0.13	0.15
		153 (22.2)		0.13	0.19
	110	141 (20.5)		0.15	0.22
	(15.9)	147 (21.3)	133	0.14	0.19

Table XX. Short Beam Shear Properties, "Dry" 219 K (-65° F) Temperature Test Data - Transverse (90°).

Material	Dry Strength 294 K (70° F) MPa (ksi)	Dry Strength 219 K (-65° F) GPà (msi)	Strength Retention, Percent	Moisture, Percent	
				Pretest	Posttest
		21 (3.0)		0.25	0.25
		28 (4.0)		0.22	*
PR288/T300	18.5	25 (3.7)		0.20	0.35
	(2.7)	25 (3.7)	135	0.22	0.30
		45.5 (6.6)		0.30	0.37
		48 (7.0)		0.22	0.27
PR288/S-Glass	30.2	38 (5.8)		0.23	0.27
	(4.4)	44 (6.4)	145	0.25	0.30

*Large portion of specimen lost.

Table XXI. Flexural Strength Properties, "Wet" 294 K (70° F) Temperature Test Data - Unidirectional (0°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet	Dry	Wet	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	1633 (236.8)	1610 (233.4) 1651 (239.4) 1528 (221.6) 1596 (231.5)	119 (17.25)	119 (17.8) 122 (17.66) 118 (17.07) 119 (17.30)	97.7	100	2.70 2.58 2.59 2.62	2.70 2.55 2.49 2.58
SP313/T300	1668 (241.9)	1613 (234.0) 1638 (237.6) 1672 (242.5) 1641 (238.0)	112 (16.23)	112 (16.21) 108 (15.64) 113 (16.42) 111 (16.09)	98.4	99.0	2.25 2.31 2.30 2.29	2.21 2.27 2.28 2.25
NR150A2/T300	1760 (255.1)	1946 (282.3) 1915 (277.7) 1355 (196.5) 1739 (252.2)	136 (19.77)	135 (19.6) 136 (19.75) 129 (18.67) 133 (19.34)	98.8	97.8	0.75 0.69 1.04 0.83	0.74 0.67 0.96 0.79
PR288/S-Glass	1520 (220.5)	1003 (145.6) 939 (136.2) 969 (140.6) 970.7 (140.8)	53.4 (7.75)	55.5 (8.05) 55.0 (7.98) 54.7 (7.94) 55.1 (7.99)	63.9	103.1	2.04 2.00 2.06 2.03	2.03 1.99 2.06 2.03
SP313/S-Glass	1849 (268.1)	1202 (174.4) 1259 (182.6) 1254 (182.0) 1239 (179.7)	57.3 (8.31)	57.6 (8.35) 58.3 (8.46) 58.0 (8.41) 58.0 (8.41)	67.0	101.2	1.42 1.48 1.42 1.44	1.41 1.47 1.41 1.43
NR150A2/S-Glass	1656 (240.1)	1125 (163.1) 1223 (177.4) 1133 (164.4) 1160 (168.3)	51.8 (7.51)	45.9 (6.65) 51.6 (7.48) 56.6 (8.21) 51.4 (7.45)	70.0	99.2	0.95 0.88 0.97 0.93	0.93 0.84 0.91 0.89

Table XXII. Flexural Strength Properties, "Wet" 294 K (70° F) Temperature Test Data - Transverse (90°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet	Dry	Wet	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	36.5 (5.3)	32.3 (4.7) 29.8 (4.3) 30.5 (4.4) 30.8 (4.5)	9.0 (1.31)	7.2 (1.05) 7.4 (1.08) 7.8 (1.13) 7.5 (1.09)	85.0	83.2	2.58 2.59 2.59 2.59	2.58 2.58 2.59 2.58
SP313/T300	43.4 (6.3)	32.7 (4.7) 32.0 (4.6) 32.5 (4.7) 32.4 (4.7)	9.8 (1.42)	8.6 (1.25) 8.8 (1.27) 8.8 (1.25) 8.7 (1.26)	74.7	88.7	2.12 2.11 2.25 2.16	2.13 2.11 2.25 2.16
NR150A2/T300	82.8 (12.0)	47.1 (6.8) 54.8 (8.0) 61.8 (9.0) 54.6 (7.9)	9.9 (1.44)	9.2 (1.33) 9.6 (1.39) 9.8 (1.43) 9.5 (1.38)	65.8	95.8	0.83 0.89 0.90 0.87	0.82 0.86 0.80 0.83
PR288/S-Glass	66.2 (9.9)	52.8 (7.7) 52.1 (7.6) 49.1 (7.1) 51.3 (7.4)	14.5 (2.11)	10.8 (1.57) 10.3 (1.49) 10.8 (1.57) 10.6 (1.54)	75.5	73.0	2.25 2.24 2.14 2.21	2.24 2.23 2.12 2.20
SP313/S-Glass	89.6 (13.0)	65.4 (9.5) 64.1 (9.3) 65.4 (9.5) 65.0 (9.4)	19.4 (2.82)	17.9 (2.59) 16.4 (2.38) 16.8 (2.44) 17.0 (2.47)	72.4	87.6	1.18 1.30 1.27 1.25	1.18 1.30 1.26 1.25
NR150A2/S-Glass	70.3 (10.2)	52.5 (7.6) 48.1 (7.0) 48.1 (7.0) 49.6 (7.2)	12.3 (1.79)	10.9 (1.58) 11.4 (1.66) 10.2 (1.48) 10.8 (1.57)	70.2	87.7	0.83 0.83 0.73 0.80	0.82 0.82 0.70 0.78

Table XXIII. Flexural Strength Properties, "Wet" 394 K (250° F) Temperature Test Data - Unidirectional (0°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet	Dry	Wet	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	1138 (165.0)	479 (69.5) 438 (63.6) 550 (79.8) 489 (70.9)	172 (16.26)	67.4 (9.77) 67.3 (9.76) 81.9 (11.88) 72.2 (10.47)	43	64.4	2.60 2.61 2.55 2.58	2.25 2.26 2.23 2.23
SP313/T300	1437 (208.4)	1171 (169.8) 1106 (106.5) 1205 (174.8) 1160 (168.4)	112 (16.23)	104 (15.09) 105 (15.24) 110 (15.94) 106 (15.42)	80.8	95	2.23 2.26 2.28 2.26	1.89 1.94 1.92 1.92
NR150A2/T300	1838 (266.5)	1897 (275.1) 1799 (260.9) 1834 (266.0) 1844 (267.4)	139 (20.16)	149 (21.67) 151 (21.95) 149 (21.61) 150 (21.74)	100	147	0.76 0.79 0.73 0.76	0.42 0.49 0.52 0.48
PR288/S-Glass	1071 (155.4)	612 (88.7) 603 (87.5) 622 (90.2) 612 (88.8)	53.2 (7.7)	39.9 (5.79) 39.3 (5.70) 38.9 (6.65) 39.4 (5.71)	57.2	74	1.98 2.08 2.08 2.05	1.62 1.70 1.72 1.68
SP313/S-Glass	1570 (227.7)	1036 (150.3) 1044 (151.4) 998 (144.8) 1026 (148.8)	58 (8.42)	57.2 (8.29) 54.2 (7.86) 58.8 (8.53) 56.7 (8.23)	65.4	97.7	1.39 1.48 1.55 1.47	1.14 1.19 1.30 1.21
NR150A2/S-Glass	1323 (191.9)	913 (132.4) 1187 (172.2) 991 (143.8) 1031 (149.5)	47.9 (6.95)	45.4 (6.59) 52.4 (7.60) 46.3 (6.72) 48.1 (6.97)	77.9	100	0.95 0.84 0.99 0.93	0.65 0.58 0.66 0.63

Table XXIV. Flexural Strength Properties, "Wet" 394 K (250° F) Temperature Test Data - Traverse (90°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet	Dry	Wet	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	41.8 (6.06)	12.5 (1.8) 11.0 (1.6) 10.8 (1.6) 11.4 (1.6)	3.86 (0.56)	1.4 (0.21) 1.3 (0.19) 1.5 (0.22) 1.4 (0.21)	27.2	37.6	2.57 2.59 2.67 2.61	2.15 2.18 2.21 2.18
SP313/T300	46.7 (6.8)	17.4 (2.5) 18.1 (2.6) 18.3 (2.7) 18.0 (2.6)	7.24 (1.05)	4.3 (0.63) 4.3 (0.62) 4.9 (0.71) 4.5 (0.65)	38.5	61.9	2.15 2.21 2.10 2.15	1.80 1.88 1.76 1.81
NR150A2/T300	80.9 (11.8)	59.4 (8.6) 48.9 (7.1) 54.5 (7.9) 54.3 (7.9)	9.65 (1.4)	8.5 (1.24) 8.0 (1.16) 8.5 (1.23) 8.3 (1.21)	67.0	86.4	0.78 0.87 0.81 0.82	0.60 0.63 0.58 0.60
PR288/S-Glass	52.5 (7.6)	16.4 (2.4) 16.5 (2.4) 16.5 (2.4) 16.5 (2.4)	5.93 (0.86)	2.0 (0.29) 2.1 (0.30) 2.2 (0.32) 2.1 (0.30)	31.5	34.9	2.20 2.18 2.21 2.20	1.73 1.69 1.72 1.71
SP313/S-Glass	85.5 (12.4)	24.9 (3.6) 24.5 (3.6) 24.9 (3.6) 24.8 (3.6)	13.3 (1.93)	7.6 (1.10) 9.1 (1.17) 9.4 (1.36) 8.3 (1.21)	29	64.7	1.29 1.27 1.32 1.29	1.00 0.99 1.03 1.01
NR150A2/S-Glass	61.4 (8.9)	41.9 (6.1) 46.4 (6.7) 42.9 (6.2) 43.7 (6.3)	10.0 (1.45)	9.3 (1.35) 8.8 (1.28) 8.2 (1.19) 8.8 (1.27)	71.2	87.6	0.83 0.77 0.87 0.82	0.66 0.53 0.62 0.60

Table XXV. Short Beam Shear Properties "Wet" 294 K (70° F) Temperature Test Data – Unidirectional (0°).

Material	Dry Strength MPa (ksi)	Wet Strength GPa (msi)	Strength Retention, Percent	Moisture, Percent Pretest	Moisture, Percent Posttest
PR288/T300	102 (14.8)	78.3 (11.4)		2.70	2.67
	101 (14.6)	75.4 (11.0)		2.81	2.81
	100 (14.5)	[illegible] (11.4)		2.93	2.93
	101 (14.7)	77.4 (11.2)	76	2.81	2.80
SP313/T300	120 (17.4)	96.5 (14.0)		2.19	2.14
	111 (16.2)	93.6 (13.6)		2.13	2.13
	116 (16.8)	93.5 (13.6)		2.25	2.25
	116 (16.8)	945 (13.7)	82	2.19	2.17
NR150A2/T300	118 (17.2)	107 (14.5)		1.05	1.05
	113 (16.4)	115 (16.6)		0.91	0.91
	119 (17.3)	108 (15.7)		0.83	0.83
	117 (16.9)	110 (15.9)	94	0.93	0.93
PR288/S-Glass	110 (16.0)	77.9 (11.3)		1.99	1.99
	105 (15.2)	81.2 (11.8)		2.16	2.12
	114 (16.6)	80.7 (11.7)		2.01	2.01
	110 (15.9)	80.5 (11.7)	73	2.05	2.04
SP313/S-Glass	104 (15.1)	95.1 (13.8)		1.38	1.36
	109 (15.9)	90.5 (13.1)		1.58	1.58
	103 (14.9)	97.6 (14.2)		1.46	1.44
	105 (14.3)	94.4 (13.7)	90	1.47	1.36
NR150A2/S-Glass	78.6 (11.4)	69.2 (10.0)		0.73	0.69
	76.5 (11.1)	65.4 (9.5)		0.69	0.67
	82.1 (11.9)	68.2 (9.9)		0.70	0.66
	79.1 (11.5)	67.6 (9.8)	85	0.71	0.67

Table XXVI. Short Beam Shear Properties "Wet" 294 K (70° F) Temperature Test Data - Transverse (90°).

Material	Dry Strength MPa (ksi)	Wet Strength GFa (msi)	Strength Retention, Percent	Moisture, Percent	
				Pretest	Posttest
PR288/T300	19.9 (3.0)	8.8 (1.3)		2.59	2.54
	15.2 (2.2)	9.9 (1.4)		2.76	2.73
	19.8 (2.9)	10.8 (1.6)		2.71	2.63
	18.1 (2.6)	9.9 (1.4)	53	2.69	2.63
SP313/T300	28.8 (4.2)	10.1 (1.5)		2.29	2.29
	21.6 (3.1)	11.8 (1.7)		2.22	2.13
	23.6 (3.4)	8.2 (1.2)		2.31	2.31
	24.7 (3.6)	10.0 (1.5)	40	2.27	2.24
NR150A2/T300	34.8 (5.0)	17.1 (2.5)		0.91	0.94
	30.4 (4.4)	24.1 (3.5)		0.83	0.83
	36.9 (5.4)	20.5 (3.0)		0.94	0.97
	34.0 (4.9)	20.6 (3.0)	60	0.89	0.91
PR288/S-Glass	31.2 (4.5)	21.2 (3.1)		2.38	2.38
	27.2 (4.0)	17.2 (3.0)		2.48	2.40
	32.3 (4.7)	16.3 (2.4)		2.41	2.37
	30.2 (4.4)	18.2 (2.6)	60	2.42	2.38
SP313/S-Glass	26.7 (3.9)	9.5 (1.4)		1.61	1.59
	30.1 (4.4)	12.2 (1.8)		1.62	1.57
	27.0 (4.0)	13.5 (2.0)		1.55	1.55
	27.9 (4.1)	11.7 (1.7)	42	1.57	1.57

Table XXVII. Short Beam Shear Properties "Wet" 394 K (250° F) Temperature Test Data - Unidirectional (0°).

Material	Dry Strength MPa (ksi)	Wet Strength GPa (msi)	Strength Retention, Percent	Moisture, Percent	
				Pretest	Posttest
PR288/T300	54.7 (7.9)	26.1 (3.8)		2.58	2.00
	53.5 (7.8)	27.0 (3.9)		2.70	2.15
	54.8 (8.0)	28.1 (4.1)		2.78	2.17
	54.3 (7.9)	27.0 (4.0)	50	2.69	2.11
SP313/T300	70.5 (10.2)	45.6 (6.6)		2.16	1.66
	71.3 (10.3)	46.3 (6.7)		2.16	1.84
	71.9 (10.4)	47.2 (6.8)		2.11	1.64
	71.2 (10.3)	46.4 (6.7)	65	2.14	1.71
NR150A2/T300	82.7 (12.0)	78.1 (11.3)		0.62	0.32
	83.8 (12.2)	74.6 (10.9)		0.61	0.30
	79.4 (11.5)	80.5 (11.7)		0.75	0.44
	82.0 (11.9)	77.7 (11.3)	95	0.66	0.35
PR288/S-Glass	60.3 (8.7)	25.6 (3.7)		1.99	1.45
	63.6 (9.2)	25.2 (3.7)		2.02	1.41
	65.0 (9.4)	25.2 (3.7)		2.01	1.60
	63.0 (9.1)	25.3 (3.7)	40	2.01	1.49
SP313/S-Glass	83.6 (12.1)	44.5 (6.5)		1.31	0.94
	83.8 (12.2)	44.9 (6.5)		1.43	1.05
	84.5 (12.3)	45.1 (6.5)		1.39	1.00
	84.0 (12.2)	44.8 (6.5)	53	1.38	1.00
NR150A2/S-Glass	60.7 (8.8)	47.8 (6.9)		0.88	0.62
	56.7 (8.2)	46.1 (6.7)		0.95	0.55
	58.1 (8.4)	49.7 (7.2)		0.81	0.57
	58.5 (8.5)	47.9 (6.9)	82	0.88	0.58

Table XXVIII. Short Beam Shear Properties "Wet" 394 K (250° F) Temperature Test Data - Transverse (90°).

Material	Dry Strength MPa (ksi)	Wet Strength GPa (msi)	Strength Retention, Percent	Moisture, Percent Pretest	Moisture, Percent Posttest
PR288/T300	15.7 (2.3)	6.3 (0.910)		2.54	2.04
	16.9 (2.5)	6.5 (0.940)		2.51	1.99
	19.8 (2.9)	6.5 (0.940)		2.52	2.03
	17.4 (2.5)	6.4 (0.930)	37	2.52	2.02
SP313/T300	18.9 (2.7)	7.2 (1.1)		2.14	1.69
	26.7 (3.9)	9.9 (1.4)		2.40	1.80
	19.7 (2.9)	10.7 (1.6)		2.44	[illegible]
	21.8 (3.2)	9.3 (1.3)	43	2.33	1.75
NR150A2/T300	38.3 (5.6)	16.3 (2.4)		0.86	0.50
	24.8 (3.6)	13.8 (2.0)		0.84	0.44
	32.1 (4.7)	16.4 (3.4)		0.84	0.53
	31.8 (4.6)	15.5 (2.3)	49	0.85	0.49
PR288/S-Glass	22.9 (3.3)	11.2 (1.6)		2.32	1.46
	21.4 (3.1)	10.0 (1.5)		2.39	1.54
	23.2 (3.4)	9.5 (1.4)		2.22	1.49
	22.5 (3.3)	10.2 (1.5)	45	2.31	1.50
SP313/S-Glass	26.5 (3.8)	8.9 (1.3)		1.53	1.04
	25.0 (3.6)	9.4 (1.4)		1.42	0.90
	25.0 (3.6)	10.8 (1.6)		1.54	0.98
	25.5 (3.7)	9.7 (1.4)	38	1.50	0.97
NR150A2/S-Glass	21.0 (3.1)	13.4 (2.0)		0.98	0.76
	21.1 (3.2)	12.6 (1.8)		0.99	0.76
	20.9 (3.0)	13.2 (1.9)		0.85	0.72
	21.3 (3.1)	13.1 (1.9)	61	0.94	0.75

Table XXIX. Flexural Strength Properties, "Wet Spike" 294 K (70° F) Temperature Test Data - Unidirectional (0°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet Spike	Dry	Wet Spike	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	1633 (236.8)	1628 (236.1) 1584 (229.8) 1659 (240.6) 1624 (234.5)	119 (17.25)	119 (17.25) 117 (17.00) 119 (17.19) 118 (17.15)	99.0	99.4	2.47 2.51 2.45 2.48	2.47 2.51 2.44 2.48
SP313/T300	1668 (241.9)	1693 (245.6) 1504 (218.2) 1604 (232.7) 1601 (232.2)	1[illegible]2 (16.23)	114 (16.59) 108 (15.64) 112 (16.19) 111 (16.14)	96.0	99.4	2.03 2.05 2.03 2.03	2.03 2.00 2.01 2.01
NR150A2/T300	1759 (256.1)	1983 (287.6) 1912 (277.3) 2070 (300.2) 1988 (288.3)	136 (19.77)	149 (21.54) 147 (21.26) 149 (21.60) 148 (21.47)	113	108	0.71 0.70 0.61 0.67	0.74 0.72 0.47 0.64
PR288/S-Glass	1520 (220.5)	1041 (151.0) 1020 (148.00 1049 (152.1) 1037 (150.3	53.4 (7.75)	55.6 (8.07) 54.6 (7.92) 54.6 (7.92) 68.2	68.2	1.80	1.80 1.79 1.82 1.80	1.79 1.79 1.83 1.80
SP313/S-Glass	1849 (268.1)	1352 (196.0) 1293 (187 5) 1295 (187.[illegible] 1313 (190.5)	[illegible]3 ([illegible].31)	60.7 (8.80) 58.1 (8.43) 56.7 (8.22) 58.5 (8.48)	71.1	1.25	1.13 1.29 1.34 1.25	1.14 1.28 1.34 1.25
NR150A2/S-Glass	1656 (240.1)	1026 (148.6) 1134 (164.4) 1339 (194.1) 1166 (169.1)	51.8 (7.51)	48.1 (6.97) 47.1 (6.83) 52.7 (7.65) 47.7 (6.92)	70.4	92.1	0.76 0.78 0.66 0.73	0.79 0.80 0.69 0.76

Table XXX. Flexural Strength Properties, "Wet Spike" 294 K (70° F) Temperature Test Data - Transverse (90°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet Spike	Dry	Wet Spike	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	36.2 (5.3)	39.6 (5.8) 45.2 (6.6) 44.8 (6.5) 43.2 (6.3)	9.0 (1.31)	7.5 (1.09) 8.1 (1.18) 7.7 (1.11) 7.8 (1.13)	120	70	2.37 2.35 2.33 2.35	2.37 2.36 2.33 2.35
SP313/T300	43.4 (6.3)	27.6 (4.0) 31.4 (4.6) 27.6 (4.0) 28.9 (4.2)	9.8 (1.42)	8.1 (1.17) 8.8 (1.27) 8.5 (1.23) 8.4 (1.22)	66.6	85.9	1.91 1.81 1.91 1.88	1.92 1.82 1.92 1.89
NR150A2/T300	82.9 (12.0)	75.3 (10.9) 58.7 (8.5) 78.3 (11.4) 70.7 (10.3)	9.9 (1.44)	9.8 (1.42) 10.0 (1.45) 9.7 (1.40) 9.8 (1.42)	85.3	98.6	0.69 0.65 0.75 0.70	0.72 * 0.78 0.75
PR288/S-Glass	68.0 (9.7)	71.9 (10.4) 72.1 (10.5) 84.5 (12.3) 76.2 (11.1)	14.5 (2.11)	11.6 (1.68) 11.4 (1.65) 11.3 (1.64) 11.4 (1.66)	112.1	78.7	1.90 1.95 1.89 1.91	1.90 1.96 1.89 1.92
SP313/S-Glass	89.7 (13.0)	63.8 (9.3) 58.5 (8.5) 69.6 (10.1) 64.0 (9.3)	19.4 (2.82)	16.6 (2.41) 16.1 (2.34) 17.5 (2.54) 16.8 (2.43)	71.3	84.7	1.15 1.18 1.09 1.14	1.15 1.17 1.09 1.14
NR150A2/S-Glass	70.5 (10.2)	62.3 (9.0) 46.1 (6.7) 48.4 (7.0) 52.3 (7.6)	12.3 (1.79)	11.0 (1.59) 11.5 (1.67) 9.1 (1.32) 10.5 (1.53)	74.1	85.5	0.73 0.58 0.59 0.63	0.76 0.61 0.62 0.66

*Portion of specimen lost during test.

Table XXXI. Flexural Strength Properties, "Wet Spike" 394 K (250° F) Temperature Test Data - Unidirectional (0°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet Spike	Dry	Wet Spike	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	1138 (165.0)	541 (78.5) 539 (78.2) 566 (82.0) 544.7 (79.6)	112 (16.26)	66.0 (9.57) 66.0 (9.57) 63.4 (9.19) 65.1 (9.44)	48.2	58	2.35 2.36 2.76 2.49	2.19 2.21 2.59 2.36
SP313/T300	1437 (208.4)	1200 (174.1) 1227 (178.0) 1178 (170.9) 1202 (174.3)	112 (16.23)	106 (15.38) 110 (15.19) 108 (15.73) 108 (15.67)	83.7	96.5	2.11 2.10 2.14 2.12	1.93 1.90 1.96 1.93
NR150A2/T300	1838 (266.5)	1869 (271.0) 1419 (205.8) 1528 (221.6) 1605 (232.8)	139 (20.16)	147 (21.28) 148 (21.48) 144 (20.86) 146 (21.21)	87.4	105	0.69 0.63 0.67 0.66	0.57 0.56 0.57 0.57
PR288/S-Glass	1071 (155.4)	616 (89.4) 557 (83.7) 617 (89.5) 604 (87.5)	53.2 (7.72)	40.7 (5.91) 39.6 (5.74) 41.0 (5.95) 40.5 (4.87)	57.1	76	1.81 1.87 1.70 1.79	1.65 1.68 1.52 1.62
SP313/S-Glass	1570 (227.7)	1043 (151.2) 1056 (153.1) 1016 (147.4) 1038 (150.6)	58.1 (8.42)	56.5 (8.19) 57.0 (8.27) 57.1 (8.28) 56.9 (8.25)	66.1	98	1.20 1.22 1.23 1.23	1.05 1.08 1.07 1.07
NR150A2/S-Glass	1323 (191.9)	963 (139.6) 1118 (162.2) 1430 (207.3) 1170 (169.7)	47.9 (6.95)	46.3 (6.72) 50.6 (7.34) 62.4 (9.05) 53.1 (7.70)	88.4	110	0.78 0.74 0.43 0.65	0.62 0.60 0.33 0.52

Table XXXII. Flexural Strength Properties, "Wet Spike" 394 K (250° F) Temperature Test Data - Transverse (90°).

Material	Flexural Strength, MPa (ksi)		Flexural Modulus, GPa (msi)		Strength Retention, Percent		Moisture, Percent	
	Dry	Wet Spike	Dry	Wet Spike	Flexural Strength	Flexural Modulus	Pretest	Posttest
PR288/T300	41.8 (6.1)	9.5 (1.38) 9.6 (1.39) 9.5 (1.38) 9.5 (1.38)	3.9 (0.56)	1.5 (0.22) 1.5 (0.22) 1.8 (0.26) 1.6 (0.23)	22.8	41.1	2.32 2.35 2.34 2.34	2.13 2.14 2.13 2.13
SP313/T300	46.7 (6.8)	18.1 (2.6) 10.5 (1.5) 13.0 (1.9) 13.9 (2.0)	7.2 (1.05)	5.6 (0.81) 5.6 (0.81) 5.1 (0.74) 5.4 (0.79)	29.8	75.2	1.98 1.93 2.00 1.97	1.88 1.78 1.86 1.84
NR150A2/T300	81.1 (11.8)	48.5 (7.0) 63.8 (9.1) 73.2 (10.6) 61.8 (9.0)	9.7 (1.4)	8.4 (1.22) 8.7 (1.26) 8.2 (1.19) 8.4 (1.22)	76.3	87.1	0.73 0.62 0.70 0.68	0.68 0.56 0.61 0.62
PR288/S-Glass	52.5 (7.6)	17.4 (2.5) 17.5 (2.5) 17.8 (2.6) 17.6 (2.6)	5.9 (0.86)	2.3 (0.34) 2.8 (0.40) 2.4 (0.35) 2.5 (0.36)	33.5	41.9	1.91 1.90 1.87 1.89	1.71 1.66 1.67 1.68
SP313/S-Glass	85.5 (12.4)	25.8 (3.7) 22.3 (3.2) 18.8 (2.7) 22.3 (3.2)	13.3 (1.93)	8.6 (1.25) 7.9 (1.15) 8.2 (1.19) 8.3 (1.20)	26.1	62.2	1.18 1.12 1.09 1.13	1.07 1.01 0.94 1.01
NR150A2/S-Glass	61.4 (8.9)	43.3 (6.3) 44.8 (6.5) 40.5 (5.9) 42.9 (6.2)	10.0 (1.45)	8.5 (1.23) 8.8 (1.28) 8.2 (1.19) 8.5 (1.23)	69.9	84.8	0.69 0.68 0.76 0.70	0.58 0.59 0.56 0.58

Table XXXIII. Short Beam Shear Properties, "Wet Spike" 294 K (70° F) Temperature Test Data - Unidirectional (0°).

Material	Dry Strength MPa (ksi)	Wet Spike Strength GPa (msi)	Strength Retention, Percent	Moisture Percent	
				Pretest	Posttest
PR288/T300	101 (14.7)	78.8 (11.4) 79.4 (11.5) 77.2 (11.2) 78.5 (11.4)	77.6	2.38 2.37 2.36 2.37	2.40 2.39 2.36 2.38
SP313/T300	116 (16.8)	92.9 (13.5) 92.9 (13.5) 94.8 (13.8) 93.6 (13.6)	80.8	1.85 1.92 1.97 1.91	1.85 1.90 1.94 1.90
NR150A2/T300	117 (16.9)	112 (16.3) 107 (15.5) 91.6 (13.3) 104 (15.0)	88.8	0.87 0.84 0.82 0.84	0.87 0.84 0.82 0.84
PR288/S-Glass	110 (15.9)	73.7 (10.7) 78.4 (11.4) 78.9 (11.5) 77.0 (11.2)	70.1	1.71 1.76 1.64 1.70	1.71 1.76 1.64 1.70
SP313/S-Glass	105 (15.3)	94.3 (13.7) 93.4 (13.5) 95.8 (13.9) 94.5 (13.7)	89.7	1.09 1.00 1.10 1.66	1.09 1.02 1.10 1.07
NR150A2/S-Glass	79.1 (11.5)	63.9 (9.7) 58.5 (9.9) 68.5 (9.7) 67.1 (9.8)	85.4	0.56 0.36 0.38 0.43	0.58 0.34 0.35 0.42

Table XXXIV. Short Beam Shear Properties, "Wet Spike" 294K (70° F) Temperature Test Data - Transverse (90°).

Material	Dry Strength MPa (ksi)	Wet Spike Strength GPa (msi)	Strength Retention, Percent	Moisture Percent	
				Pretest	Posttest
PR288/T300	18.1 (2.6)	8.0 (1.2) 14.3 (2.1) 16.8 (2.4) 13.5 (2.0)	47.6	2.03 2.30 2.17 2.18	2.06 2.35 2.20 2.23
SP313/T300	24.7 (3.6)	10.0 (1.5) 16.7 (2.4) 9.9 (1.4) 12.2 (1.8)	49.4	1.85 1.92 1.94 1.90	1.88 1.92 1.96 1.92
NR150A2/T300	34.0 (4.9)	19.3 (2.8) 15.7 (2.3) 16.7 (2.4) 17.2 (2.5)	50.7	0.76 0.80 0.77 0.78	0.76 0.80 0.77 0.78
PR288/S-Glass	30.2 (4.4)	22.1 (3.2) 12.3 (1.8) 17.7 (2.6) 17.5 (2.5)	58.0	1.62 1.59 1.68 1.63	1.64 1.59 1.72 1.65
SP313/S-Glass	27.9 (4.1)	18.5 (2.7) 18.4 (2.7) 16.9 (2.5) 17.9 (2.6)	64.2	1.12 1.18 1.04 1.11	1.14 1.20 1.04 1.13
NR150A2/S-Glass	25.7 (3.7)	17.5 (2.5) 15.7 (2.3) 17.2 (2.5) 16.8 (2.4)	65.1	0.52 0.64 0.72 0.63	0.52 0.62 0.68 0.61

Table XXXV. Short Beam Shear Properties, "Wet Spike" 394 K (250° F) Temperature Test Data - Unidirectional (0°).

Material	Dry Strength MPa (ksi)	Wet Spike Strength GPa (msi)	Strength Retention, Percent	Moisture Percent	
				Pretest	Posttest
PR288/T300	54.3 (7.9)	27.5 (4.0) 28.2 (4.1) 28.1 (4.1) 27.9 (4.1)	51.4	2.38 2.40 2.40 2.39	2.16 2.20 2.20 2.19
SP313/T300	71.2 (10.3)	48.9 (7.1) 47.6 (6.9) 48.9 (7.1) 48.5 (7.0)	68.1	1.87 2.01 2.00 1.96	1.66 1.85 1.84 1.78
NR150A2/T300	82.0 (11.9)	76.6 (11.1) 75.8 (11.0) 71.8 (10.4) 74.7 (10.8)	91.2	0.63 0.54 0.66 0.61	0.53 0.49 0.49 0.50
PR288/S-Glass	63.0 (9.1)	26.8 (3.9) 27.8 (4.0) 27.0 (3.9) 27.2 (3.9)	43.2	1.74 1.72 1.77 1.74	1.58 1.57 1.57 1.57
SP313/S-Glass	84.0 (12.2)	49.7 (7.2) 48.5 (7.0) 47.3 (6.9) 48.5 (7.0)	57.7	1.18 1.23 1.18 1.20	1.04 1.00 1.00 1.01
NR150A2/S-Glass	58.5 (8.5)	47.8 (6.9) 50.7 (7.4) 47.0 (6.8) 48.5 (7.0)	82.8	0.44 0.33 0.48 0.42	0.27 0.17 0.27 0.24

Table XXXVI. Short Beam Shear Properties, "Wet Spike" 394 K (250° F) Temperature Test Data - Transverse (90°).

Material	Dry Strength MPa (ksi)	Wet Spike Strength GPa (msi)	Strength Retention, Percent	Moisture Percent	
				Pretest	Posttest
PR288/T300	17.4 (2.5)	5.9 (0.86) 6.5 (0.94) 6.6 (0.96) 6.3 (0.92)	46.4	2.37 2.40 2.37 2.38	2.12 2.23 2.14 2.16
SP313/T300	21.8 (3.2)	8.1 (1.2) 7.3 (1.1) 7.6 (1.1) 7.7 (1.1)	35.1	1.94 1.97 2.00 1.97	1.78 1.85 1.79 1.80
NR150A2/T300	31.8 (4.6)	15.0 (2.2) 13.3 (1.9) 18.6 (2.7) 15.7 (2.3)	49.2	0.62 0.71 0.58 0.64	0.51 0.63 0.50 0.55
PR288/S-Glass	22.5 (3.3)	10.3 (1.5) 10.9 (1.6) 10.8 (1.6) 10.7 (1.6)	47.5	1.80 1.74 1.84 1.79	1.59 1.48 1.55 1.54
SP313/S-Glass	25.5 (3.7)	8.1 (1.2) 8.9 (1.3) 7.8 (1.1) 8.3 (1.2)	32.4	1.11 1.21 1.22 1.18	0.98 1.06 1.16 1.07
NR150A2/S-Glass	21.3 (3.1)	15.7 (2.3) 14.3 (2.1) 12.7 (1.8) 14.3 (2.1)	67.0	0.62 0.62 0.52 0.59	0.48 0.53 0.31 0.44

Table XXXVII. Conditioning Effects on Short Beam Shear Properties.

Material	Short Beam Shear Properties Strength Retention Percent									
	Dry 219 K (-65° F)		Wet 294 K (70° F)		Wet 394 K (250° F)		Wet Spike 294 K (70°)		Wet Spike 394 K (250° F)	
	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0)	Trans. (90°)
PR288/T300	133	135	76	53	50	7	77.6	47.6	51.4	36.4
SP313/T300	---	---	82	40	65	43	80.8	49.4	68.1	35.1
NR150A2/T300	---	---	94	60	95	49	88.8	50.7	91.2	49.2
PR288/S-Glass	133	145	73	60	40	45	70.1	58	43.2	47.5
SP313/S-Glass	---	---	90	42	53	38	69.7	64.2	57.7	32.4
NR150A2/S-Glass			85	55	82	61	85.4	65.1	82.8	67.0

PR288/S-glass were the only materials evaluated at 219 K (-65° F) and in the 'dry' condition only (Reference Tables XVII through XX).

3.5.3.2 "Wet" Conditioned Tests

The 'wet' or complete moisture saturation of specimens was achieved by conditioning in a humidity chamber at 355 K (180° F)/97% relative humidity. Control specimens of each material and specimen design were monitored and graphically plotted to determine when full saturation was achieved as outlined in Paragraph 3.4.4. The PR288 and SP313 epoxy matrix specimens were tested after >30 days exposure but the NR150A2 matrix specimens were retained in the humidity chamber for a period of ~55 days to achieve a more stabilized saturation level. The 'wet' strength data generated is shown in Tables XXI through XXVIII and is compared to the equivalent 'dry' mechanical properties for the purpose of the strength retention percentage calculation.

3.5.3.3 "Wet Spike" Conditioned Tests

The 'wet spike' conditioning was achieved by fully saturating the specimens as described in "Wet Conditioning" and then subjecting the specimens to an abrupt 422 K (300° F) temperature excursion immediately before carrying out the appropriate mechanical properties test. Based upon the specimen heating and cooling rate study described in Paragraph 3.4.1. Each specimen was heated at 422 K (300° F) for a period of six minutes to achieve the requisite exposure of three minutes at full 422 K (300° F) temperature.

The 'wet spike' mechanical properties generated are shown in Tables XXIX through XXXVI and again are compared directly against the 'dry' data to establish percentage strength retentions.

3.6 TASK I DATA ANALYSIS

An analysis of the effects of moisture content, temperature level and temperature transients on the longitudinal and transverse short beam shear and flexural strength of six basic fiber/matrix composite laminates was conducted. Percent strength retention for each of the six materials tested at 219 K (-65° F), 294 K (70° F), and 394 K (250° F) and conditioned to the "dry," "wet," and "wet spike" state are tabulated in Tables XXXVI and XXXVIII. The percentage strength retention is based upon the particular property value of the "dry" specimen at the appropriate test temperature. In order to show the overall effects of temperature and environmental conditioning, the data are presented in bar graph form in Figures 12 through 15.

The general conclusions from the analysis of the Task I - Materials characterization study were:

- NR150A2 polyimide matrix demonstrated considerably improved moisture resistance over the two selected epoxy systems, PR288 and SP313. Nominally 75 percent less moisture was absorbed by the NR150A2/T300

Table XXXVIII. Conditioning Effects on Flexural Properties.

Material	Flexural Properties Strength Retention Percent									
	Wet 219 K (-65° F)		Wet 294 K (70° F)		Wet 394 K (250° F)		Wet Spike 294 K (70°)		Wet Spike 394 K (250° F)	
	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)	Unidir. (0°)	Trans. (90°)
PR288/T300	97	163	97.7	85	43	27.2	99.4	120	48.2	22.8
SP313/T300	---	---	88.4	74.7	80.8	38.5	96	66.6	83.7	29.8
NR150A2/T300	---	---	98.8	65.8	100	67.0	113	85.3	87.4	76.3
PR288/S-Glass	113	151	63.9	75.5	57.2	31.5	68.2	112.1	57.1	33.5
SP313/S-Glass	---	---	67	72.4	65.4	29.0	71	71.3	66.1	26.1
NR150A2/S-Glass	---	---	70	70.2	77.9	71.2	70.4	74.1	88.4	69.9

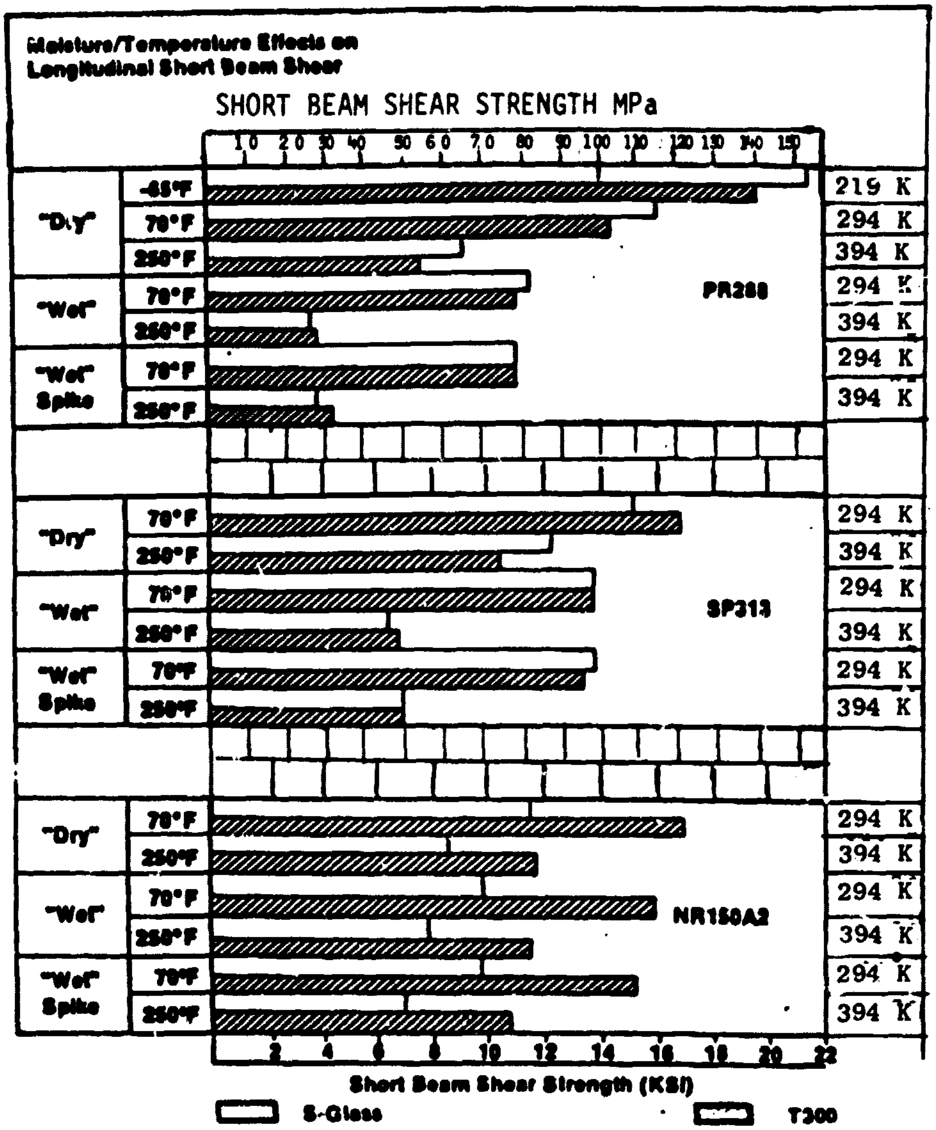


Figure 12. Moisture/Temperature Effects on Longitudinal Short Beam Shear Properties.

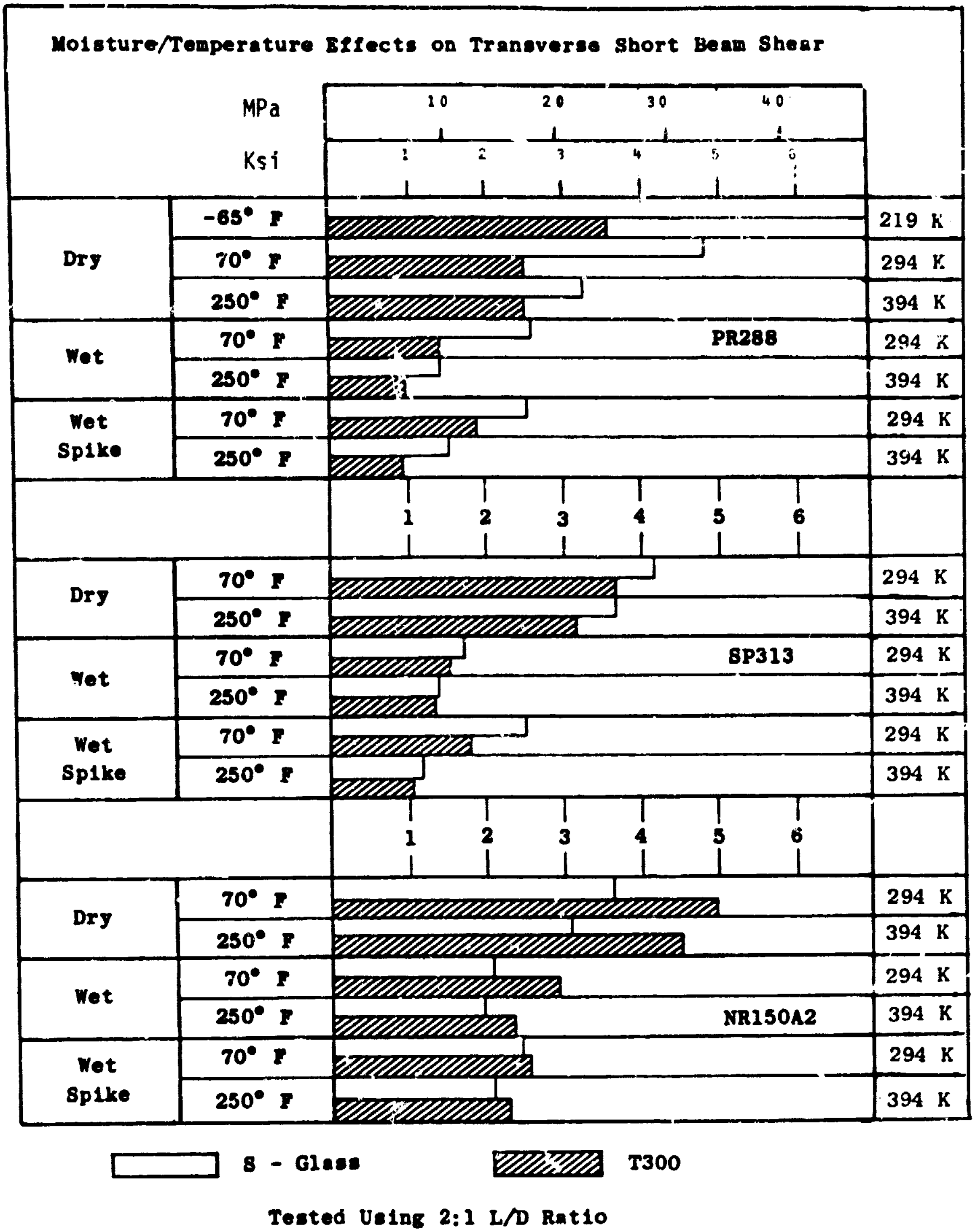


Figure 13. Moisture/Temperature Effects on Transverse Short Beam Shear Properties.

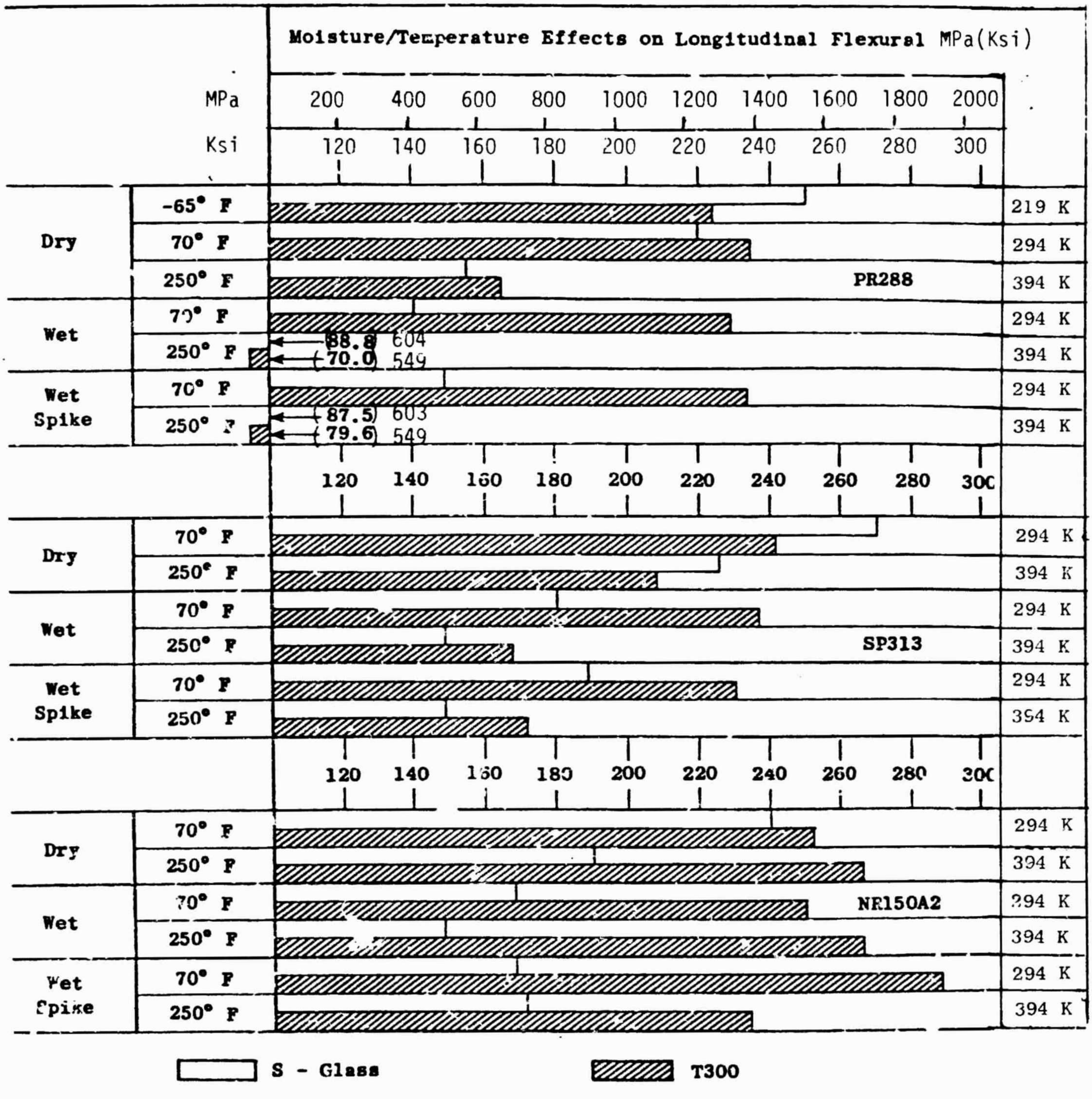


Figure 14. Moisture/Temperature Effects on Longitudinal Flexural Properties.

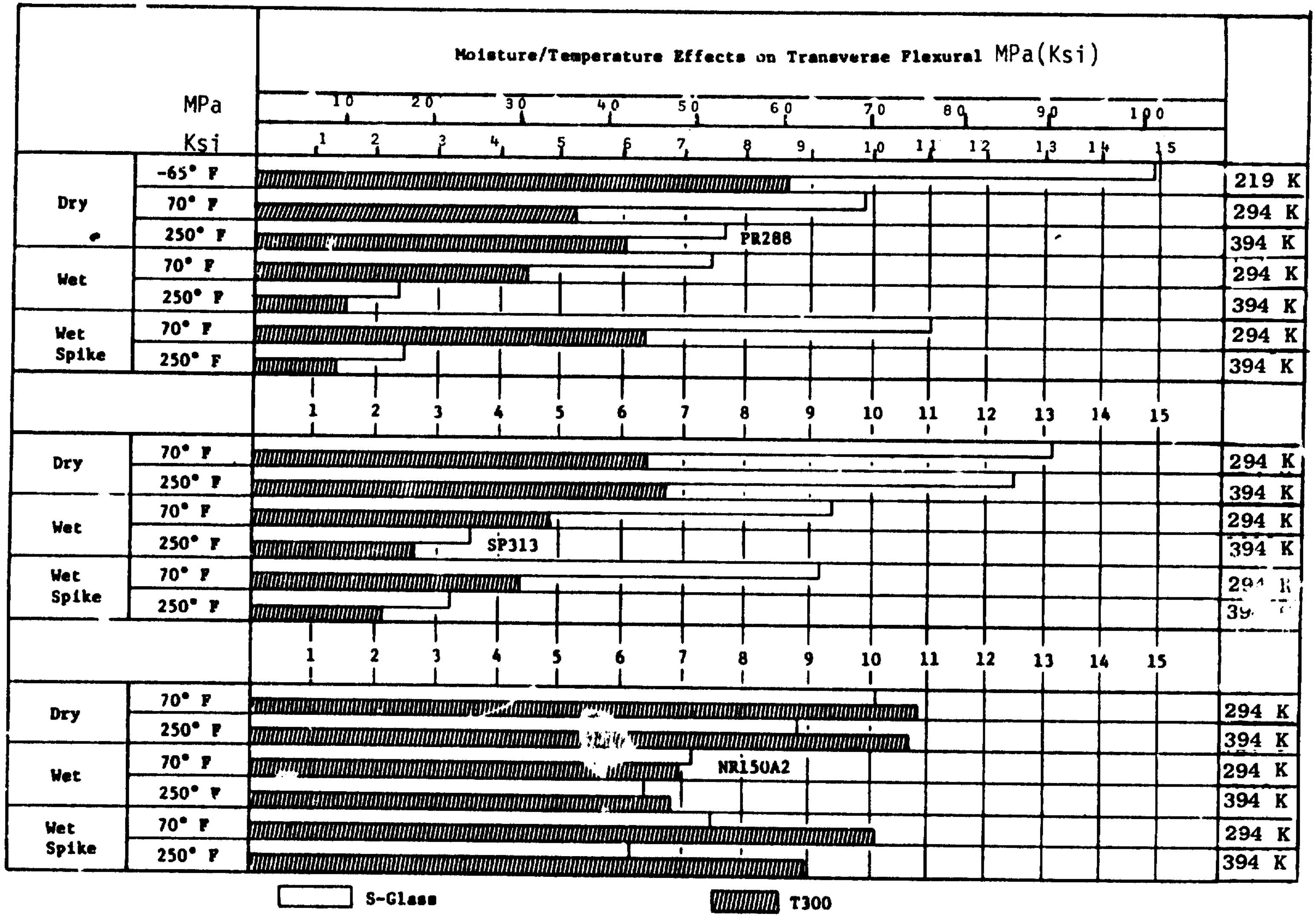


Figure 15. Moisture/Temperature Effects on Transverse Flexural Properties.

than the PR288/T300 and 60 percent less than the SP313/T300 system. (Reference Figures 3-7 through 3-10).

Moisture was absorbed initially at a faster rate in the transverse (90°) fiber predominant NR150A2 specimens indicating wicking at the matrix/fiber interface and the need for more compatible fiber finishes/sizes to achieve more intimate adhesion.

- "Dry" conditioning equivalent of three months storage at 294 K (70° F)/50% RH had no adverse effects on short beam shear or flexural properties when tested at 294 K (70° F) and 394 K (250° F).

- Short Beam Shear and Flexural properties of the "dry" PR288 matrix materials increased some 30 percent when tested at 219 K (-65° F) due to the higher tensile properties of the resin at the lower temperature.

- Wet and wet spike conditioned T300 specimens indicate negligible effect on dry properties caused by moisture when tested at room temperature. S-glass composites, however, indicate 30 percent reduction in the 294 K (70° F) properties.

- Elevated temperature tests 394 K (250° F) illustrate the moisture plasticizing effect on the resin matrices. The PR288, which is nominally a 394 K (250° F) capability system is more severely affected by moisture saturation, retaining only 40-50 percent of its "dry" elevated temperature (0°) orientation short beam shear and flexural properties. The transverse (90°) which are matrix controlled retain only 25-35 percent. The higher temperature capability systems, SP313 (450 K [350° F]) and NR150A2 (533 K [500° F]) show reduced falloff in 0° orientation mechanical properties at 394 K (250° F) since the test temperature is below the glass transition temperature (Tg) of the resins. Similar reduction in properties to the PR288 would be anticipated with the SP313 when tested at 450 K (350° F) or NR150A2 at 533 K (500° F).

The NR150A2 composite systems exhibit extremely high transverse (90°) flexural strength properties compared to the PR288 and SP313 epoxy systems [82.7 MPa (12 ksi) versus 41.4 MPa (6 ksi) at room temperature]. An even greater differential exists at 394 K (250° F) on the wet and wet spike conditioned specimens when a 55-62 MPa (8-9 ksi) 0° orientation transverse flexural value is maintained with the NR150A2/T300 compared to the 10-17 MPa (1.5-2.5 ksi) for the epoxy systems. High transverse flexural properties translated into flatwise tensile properties (through the thickness) in accordance with C Chamis' (NASA-Lewis) theory (flatwise tensile = 60 percent transverse flexural) should yield 55 MPa (8 ksi) at room temperature or a 2:1 improvement over the PR288 system. The potential improvement in the NR150A2 flatwise tensile characteristics compared to PR288 reflected in improved impact capabilities for the system in the Task II ballistic impact tests.

4.0 TASK II - BALLISTIC IMPACT TESTS

The effects of temperature level, moisture, and temperature transients on the ballistic impact resistance of selected composite materials were evaluated during this task. Candidate materials based on the results of Task I were combined to form three hybrid and two superhybrid systems in addition to a baseline PR288/T300 system. A "superhybrid" composite material concept was identified by NASA a few years ago (NASA TND-7879) and NASA TMX-71836) and consists of a variety of structural reinforcements combined into a single material structure with each contributing its unique features. The typical superhybrid composite combines the strength of weight features of the polymeric materials. The high stiffness characteristics of boron-aluminum and the local toughness of titanium. The three materials are combined in a unique arrangement using adhesives to bond the metallic foils to each other and to the polymeric composite structural core. Eighty simulated, nine-inch-long blade specimens employing a constant double wedge section of four inches chord were fabricated and ballistically impacted. Figure 16 shows typical hybrid and superhybrid specimens fabricated for Task III tests. Gelatin projectiles were fired at relative velocities and impact angles to simulate local impact forces and stresses on the panels typical of bird impacts. The environmentally conditioned specimens were tested at 219 K (-65° F), 294 K (70° F), and 394 K (250° F). Evaluation of the impact damage was carried out by nondestructive inspection (NDE), change in torsional stiffness, in addition to visual observations and high speed motion pictures of selected tests.

4.1 Material Selection

The materials used in Task II were essentially defined by NASA except for the mixture ratio of T300 and S-glass in the hybrid composites and the selection of the composite materials to be employed in the two superhybrids.

4.1.1 Glass/Graphite Fiber Ratio

General Electric hybridizing studies in the 1970-71 time period identified that an 80:20 ratio of graphite/S-glass intraplied hybrid achieved the desired improved impact characteristics of basic graphite composites with the minimum penalty on density, modulus, shear and flexural properties. Figure 17 illustrates the effect of graphite to glass fiber ratio on Charpy impact characteristics. Tables XXXIX and XL summarize some of the data generated at General Electric during hybrid composition evaluations. Numerous blades and FOD test panels have been fabricated using the 80:20 ratio of graphite/S-Glass intgraplied fiber reinforcement and have been subjected to high velocity ballistic impact tests on whirligig and static impact facilities to confirm the effective impact resistance of this type of construction.

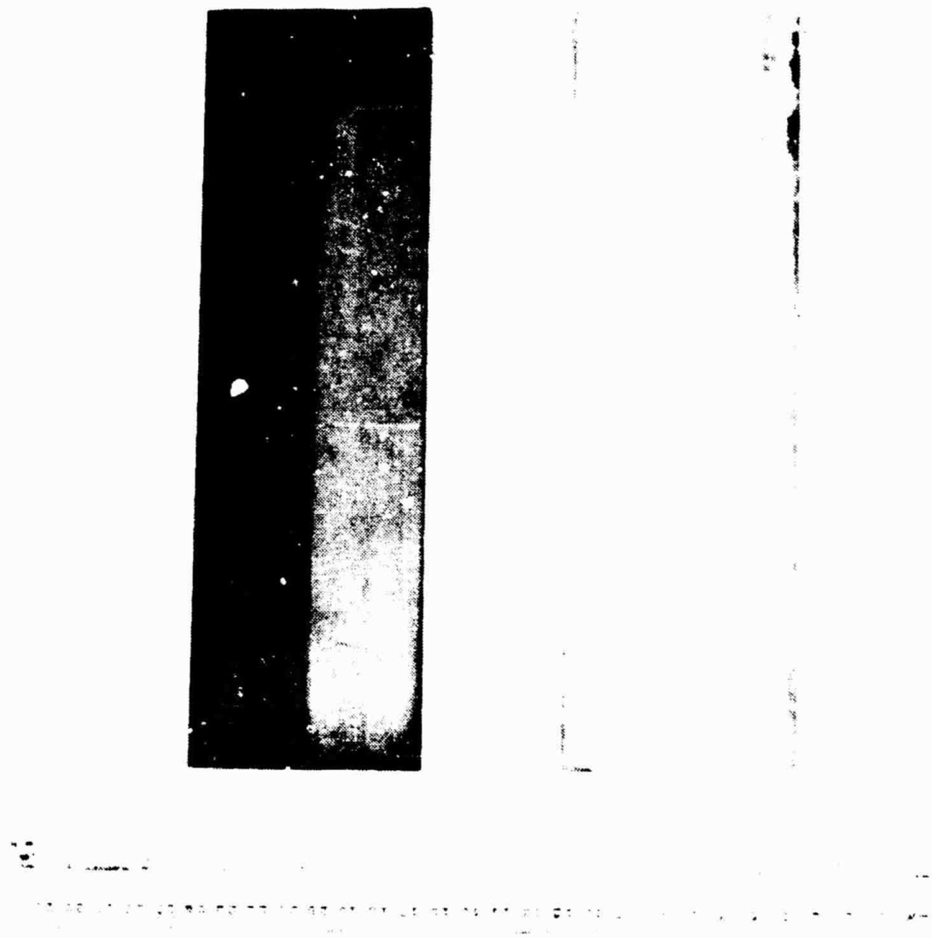


Figure 16. Typical Task II Hybrid and Superhybrid Specimens.

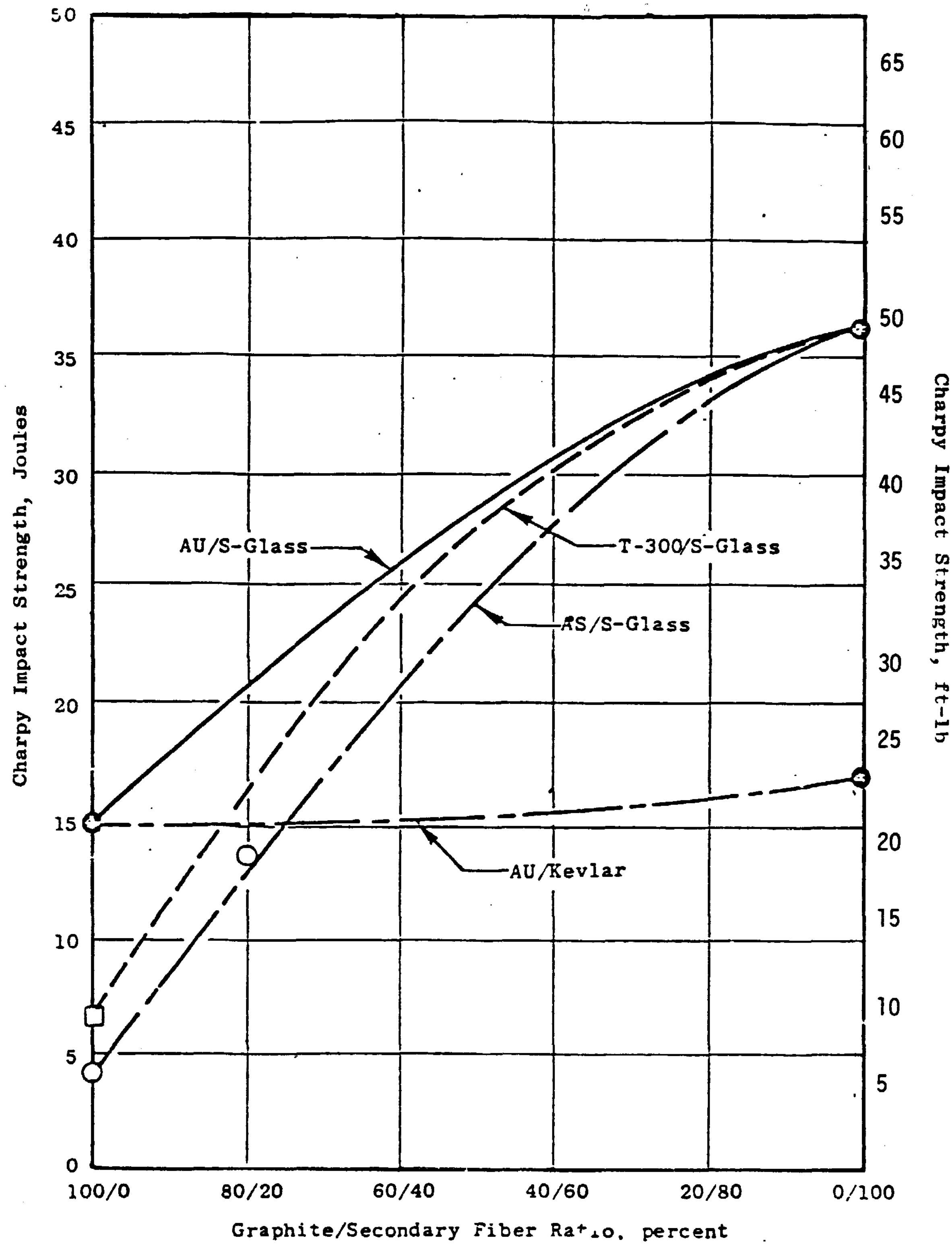


Figure 17. Effect of Primary/Secondary Fiber Ratio on Charpy Impact Strength of Selected Hybrid Systems.

Table XXXIX. Hybrid Composite Mechanical Property Data.

Resin	PR288									
Fiber(s)	AU/AS Intraply	AU/AS Intraply	AU/AS Kevlar Intraply	AU/AS S-Glass Intraply	AU/Kevlar Intraply	AU/Kevlar Intraply	AU/Kevlar Intraply	AU/S-Glass Intraply	AS/Kevlar Intraply	AS/S-Glass Intraply
Construction	50/50	50/50	40/40/20	40/40/20	80/20	60/40	50/50	80/20	80/20	80/20
Flexural Strength MPa(ksi)										
RT	1986(288)	1882(273)	---	---	1731(251)	1441(209)	1475(214)	1834(266)	---	1503(218)
394 K (250° F)	1489(216)	1627(236)	---	---	1145(166)	924(134)	1062(154)	1338(194)	---	1400(203)
Flexural Modulus GPa(msi)										
RT	123(17.8)	127(18.4)	---	---	108(15.7)	96(13.9)	92(13.4)	108(15.7)	---	102(14.8)
394 K (250° F)	119(17.2)	119(17.2)	---	---	99(14.4)	90(13.0)	90(13.0)	103(14.9)	---	99(14.4)
Shear Strength MPa(Ksi)										
RT	93(13.5)	93(13.5)	76(11.0)	61(8.9)	68(9.8)	57(8.3)	71(10.3)	72(10.5)	86(12.5)	105(15.2)
394 K (250° F)	52(7.5)	73(10.6)	51(7.4)	54(7.5)	52(7.5)	46(6.7)	51(7.1)	49(7.1)	65(9.4)	66(9.6)
Charpy Impact Strength Joules (ft-lb)	18.6(13.7)	19.1(14.1)	12.4(9.0)	19.0(21.4)	19.3(14.2)	20.6(15.2)	---	26.3(19.4)	9.8(7.2)	19.1(14.1)
Total Fiber Vol., Percent	60.8	60.8	56.1	58.5	60.1	59.5	64.3	59.6	59.7	59.2
Specific Gravity g/cm3	1.59	1.59	1.60	1.68	1.54	1.49	1.48	1.67	1.53	1.66

Table XL. Room Temperature Mechanical Property Test Results for Various PR288 Composite System.

Material System	SBS STR. (0) MPa(ksi)	SBS STR. 0/35/0/-35) MPa(ksi)	90° SBS STR. (0/35/0/-35) MPa(ksi)	Flat. Ten. (0/22/0/-22) MPa(ksi)	Charpy (0/22/0/-22) J(ft-lbs)
PR288/AU	60(8.7)	48(6.9)	18(2.6)	8(1.2)	17.4(12.8)
PR288/AS	110(15.9)	91(13.2)	26(3.8)	28(4.0)	5.8(4.3)
PR288/T300	104(15.1)	91(13.2)	22(3.2)	21(3.1)	8.0(5.9)
PR288/Boron	99(14.3)	83(12.0)	12(1.8)	26(3.7)	6.2(4.6)
PR288/ALS	90(13.0)	90(13.0)	26(3.7)	25(3.6)	8.9(6.6)
PR288/AU/Kevlar	62(9.0)	44(6.4)	12(1.7)	8(1.2)	18.8(13.9)
PR288/AS/Kevlar	86(12.5)	65(9.4)	21(3.1)	14(2.0)	9.8(7.2)
PR288/AU/S-glass	47(6.8)	43(6.2)	17(2.5)	13(1.9)	22.2(16.4)
PR288/AS/S-glass	102(14.8)	92(13.3)	28(4.0)	23(3.4)	19.1(14.1)
PR288/T300/S-glass	101(14.7)	89(12.9)	23(3.4)	28(4.1)	23.6(17.4)
PR288/AU/AS	75(10.9)	50(7.3)	17(2.4)	12(1.8)	12.5(9.2)
PR288/AU/AS/Kevlar	76(11.0)	48(7.0)	90(3.0)	11(1.6)	12.2(9.0)
PR288/AU/AS/S-glass	61(8.9)	54(7.8)	18(2.6)	14(2.0)	29.0(21.4)

Based upon the Task I, Material Characterization, results, S-glass composites shear and flexural properties are degraded more severely by moisture absorption than T300 and, therefore, it was advantageous to keep the S-glass percentage to a minimum in the hybrid composites.

The hybrid materials used in Task II were based upon a 80:20 ratio of T300/S-glass of an intraplied construction while maintaining a total fiber volume fraction in the molded composite of sixty percent.

4.1.2 Superhybrid Composite Materials

The polymeric composite materials selected for the superhybrid test specimens were:

Superhybrid A PR288/T300(80)/S(20)

Superhybrid B SP313/T300(80)/S(20)

NR150A2 matrix as a potential candidate for superhybrid construction was eliminated for two major reasons:

1. Difficulty in removing the solvents during cocuring processing in view of the impervious outer layers of titanium and boron/aluminum preventing the necessary outgassing during staging. The core preform could have been staged separately to partially remove the solvents prior to the application of the outer metallic layers, but this would have reduced the wetability of the resin to the foil surfaces and thereby inhibited the bonding characteristics. NR150 resin primers no doubt could have been developed to improve the wetability, but this would have involved extensive materials and process development to ensure adequate adhesion. The concern was that at this present stage, inferior specimens could have been produced which may have inadvertently condemned NR150.

2. Thermal mismatch in expansion coefficients of the metallic foils and the composite material was also a concern. The high processing temperatures [589 K (600° F)] involved with the NR150 system would have created high thermal stresses at the titanium to boron/aluminum to graphite composite bonded interfaces during cooling down from the molding temperature to room temperature. These thermal stresses, coupled with the induced impact loads, would have jeopardized the impact resistance of this combination of materials. It was essential to develop curing temperatures for resin matrices which were slightly in excess of the operating conditions for a graphite or combined graphite/metallic component such that, upon raising to the operational temperature, the thermal stresses are negated. Alternative solvents and processing temperatures in the 422 K (300° F) region could have been developed for the NR150 but would have needed additional effort beyond the scope of this program.

Metallic Foils

The boron/aluminum foils selected for the superhybrid specimen construction were composed of 0.14 mm (0.0056 in.) diameter boron filament and 1100 aluminum matrix. The material was procured as a prebonded monotape 0.19 ± 0.005 mm (0.0074 ± 0.0002 in.) thick, yielding a fiber volume fraction of 47.5 ± 2.5 percent. The titanium foil outer skins of the superhybrid specimens were produced from Titanium 6Al-4V sheet stock chemically etched down to the appropriate thickness requirements.

4.1.3 Adhesives

Adhesive films were employed in the superhybrid specimens at the interfaces between the titanium to boron/aluminum and the boron/aluminum to polymeric composite core. PR288/S-Glass and SP313/S-glass prepregs were initially scheduled as the selected adhesive films in view of the common curing, flow, and molding characteristics with the polymeric core materials. During the execution of the Superhybrid Blade Program, NAS3-20402, tougher, higher peel strength adhesives were evaluated and substituted for laminating resins planned to be employed as the adhesive. The selected cocuring foil bonding adhesives for the two superhybrid systems were the AF163 with the PR288 hybrid core and AF147 with the SP313 hybrid material construction specimens. The selection of the two adhesives was based on

- Cure compatible with composite core material.
- Nylon carrier to control glue line thickness.
- Drapeable film with reasonable tack properties.
- Lap shear properties of 27 MPa (4 ksi) at room temperature.

4.2 MATERIALS PROCUREMENT

All the intraplied hybrid prepreg tapes were purchased in accordance with the General Electric Specification 401313-485, Rev B, "Unidirectional Hybrid Fiber Preimpregnated Tape or Wide Goods." The intraplied hybrid materials were based upon an 80:20 volume ratio of T300 graphite to S-Glass, maintaining a total fiber volume fraction in the molded composite of 60 percent.

The two epoxy intraplied hybrid materials, PR288/T300/S and SP313/T300/S, together with the baseline PR288/T300, were procured from 3M Company and the polyimide intraplied hybrid, NR150A2/T300/S from Fiberite Corporation.

4.2.1 Material Quality Assurance

- PR288/T300 (Lot 785)

The material was accepted for specimen fabrication with some deviations which were outside the specification limits. The prepreg fiber weight of 128.5 gm/m^2 (0.0263 lbs/ft^2) (Ref: Table XLI, QC Data Summary) was lower than the 131 gm/m^2 (0.0268 lb/ft^2) specification lower limit which also reflected in the lower fiber volume percentage of 55.23 in the molded laminate compared to the minimum specification value of 58. Despite the lower fiber contents, the mechanical properties were within the specified limits.

- PR288/TG300/S (Lot 786)

The QC Data Summary for this material shown in Table XLII indicated that the graphite fiber content in the prepreg was 104 gms/m^2 (0.0212 lbs/ft^2) versus the minimum specification level of 105 gm/m^2 (0.0216 lbs/ft^2) which again affected the overall fiber fiber volume percentage in the molded laminate being 57.4 versus the minimum specification figure of 58. The material was released for specimen fabrication based upon acceptable mechanical properties in the molded laminate.

- SP313/T300/S (Lot 787)

Table XLIII shows the QC Data Summary Sheet which indicated the material was out of specification in prepreg fiber weight and fiber volume in the molded laminate. The room temperature short beam shear value of 87 MPa (12.6 ksi) was outside the specification limit of 97 MPa (14 ksi) which, in part, was attributable to the 1.09 percent voids in the molded QC test panel. SP313/T300 composites appeared to exhibit reduced short beam shear properties, indicating a reduced compatibility between the fiber and the resin.

- NR150A2/T300/S (Lot C8532)

The material was accepted for specimen fabrication despite deviations which were outside the specification limits. The glass fiber content was below minimum requirements, which affected the overall fiber content in the prepreg. The physical properties of the molded QC test panel indicated a higher total fiber volume percentage of 64 percent due to the reduced panel thickness of 1.8 mm (0.074 in.) The mechanical properties of the panel were within specification limits except for short beam shear values at room temperature. Table XLIV shows the QC Data Summary for this batch of material.

- Boron-Aluminum Monotape

The Boron-Aluminum prebonded monotape composed of 0.14 mm (0.0056 in.) diameter boron filament and 1100 aluminum matrix was procured from Avco Corporation to GE specification 2013155-588

Table XLI. Q.C. Data Summary - Homogeneous Prepreg.
(Specification 4013163-484)
Appendix________

Prepreg Lot No. 785 Date Received 7/13/78
Prepreg Type PR288/T300 Fiber Batch No. 498-2
Quantity 2.27 kgs (5 lbs) Resin Batch No. 619TP & 468TP

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Tensile Str.,MPa(KSI),Avg.	295(428)	--	Min.	x	
Tensile Mod.,GPa(MSI),Avg.	228(33.0)	--		x	
Density, gms/cc,Avg.	1.719				
B. Prepreg Data:					
Fiber,gms/m2(ft2)*,Avg.	127(11.8)	128.5(11.94)	136 ± 4 (12.6 ± 0.4)		x
Individual Specimens**	3/3	0/3	?/3		x
Resin,gms/m2(ft2),Avg.	85(7.9)	86(7.96)	78±4(7.3 ± 0.4)		x
Individual Specimens**	0/3	0/3	2/3		x
Vols, % Wt., Avg.	0.6	0.107	2% Max.	x	
Individual Specimens**	3/3	3/3	2/3	x	
Gel Time,Mins.@383 K(230° F)	37	47	40 min.	x	
Flow, %@383K (230° F)	--	--	--		
Visual Discrepancies					
C. Laminate Data					
Roll No.(s)		No. 1			
Gel Time in Die, Mins.		47			
Thickness, cm (in.)		2.0(0.080)	0.080 ± 0.002		
Flex. Str.@RT.,MPa(ksi)	1607(233)	1675(243)	1620(235)	x	
@394K (250° F),MPa(ksi)	1303(189)	1441(209)	1172(170)	x	
Flex. Mod.@RT,GPa(msi)	110(15.9)	115(16.67)	103(15)	x	
@394K (250° F),GPA(msi)	103(14.9)	118(17.07)	100(14.5)	x	
SBS Str.@RT,MP(KSI)	110(15.9)	112(16.19)	97(14)	x	
@394K (250° F),MPa(ksi)	67(9.17)	73(10.53)	59(8.5)	x	
Fiber Volume, %	53.6	55.23	60± 2		x
Resin Content, % Wt.	39.5	37.38	Report	x	
Voids, %		-0.41	2% Max	x	
Density, gms/cc	1.52	1.53	Report	x	
Cured Thickness per ply - mm (mils).		13mm(5.0)			

D. Material Disposition

Accept for All Usage ______. Accept for Limited Use NASA ENVIRONMENTAL PROGRAM
Reject____________and (a) Return to vendor________or (b) Scrap____________.

Q.C. Eng. G.C. Murphy Date: 7/26/78

* Fiber Wt. = 7.08 x SP.Gr. of fiber.
** No. specimens in Spec./No. specimens tested.

Table XLII. Q.C. Data Summary - Homogeneous Prepreg.

(Specification 4013163-48)

Addendum ________

Prepreg Lot No. 786

Prepreg Type PR288/T300/S

Quantity 4.54 kgs (10 lbs)

Date Received 7/13/78

Fiber Batch No. 4/13/79

Resin Batch No. 619TP

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Batch No.	498-2				
Tensile Str., MPa(ksi), Avg.	2951(428)	--	410 Min.	x	
Tensile Mod., GPa(msi), Avg.	228(33.0)	--	29 - 34	x	
Density, gms/cc, Avg.	1.719	--	1.785 - 1.827		
B. Prepreg Data:					
Graphite, gms/m2(gms/ft2) Avg	101(9.4)	104(9.64)	110±4(10.2±0.4)*		x
Individ. Specimens***	0/3	0/3	2/3		x
SecFiber, gms/m2(gms/ft2) Avg	39(3.6)	36(3.3)	38±3(3.5±0.3)***	x	
Resin, gms/m2(ft2), Avg.	3/3	3/3	2/3	x	
Tot. fiber wt. gms/m2(gms/ft2)	140(13.0)	140(13.01)	147±4(13.7±0.4)		x
Individual Specimens**	0/3	0/3	2/3	x	
Resin, gms/m2(gms/ft2) Avg.	84(7.8)	85(7.9)	79±5(7.3±0.5)	x	
Individual Spcimens***	1/3	1/3	2/3		
Vols., % Wt., Avg,	0.5	0.7	2% Max.	x	
Individ. Specimens***	3/3	3/3	2/3		x
Gel Time, Mins. 383 K (230° F)	34	20	40 Min.		x
Flow, % 383 K (230° F)	--	--	3 - 7		
Visual Discrepancies					
C. Laminate Data:					
Roll No.(s)					
Gel Time in Die, Mins.		20			
Thickness, cm (in.)		0.2(0.080)	0.080 ± 0.002	x	
Flex. Str. @RT., MPa(ksi)	1538(223)	1586(230)	1345(195)	x	
@394 K (250° F), MPa(ksi)	1310(190)	1241(180)	1172(170)	x	
Flex. Mod. @RT, GPa(msi)	101(14.6)	108(15.67)	97(14.0)	x	
@394 K (250° F), GPa(msi)	93(13.5)	107(15.49)	90(13.0)	x	
SBS Str. @RT, MPa(ksi)	108(15.7)	107(15.59)	97(14.0)	x	
@394 K (250° F), MPa(ksi)	67(9.7)	71(10.31)	59(8.5)	x	
Fiber Volume, %	43.19/11.03	45.7/11.7	48/12(60±2)		x
Resin Content, % Wt.	36.86	33.3	Report	x	
Voids, %	-0.94	-0.11	2% Max	x	
Density, gms/cc	1.61	1.63	Report	x	
Cured Thickness per ply - mm (mils).	14mm(5.0)				

D. Material Disposition:

Accept for All Usage. ________ Reject ____________ and (a) Return to

Vendor __________ or (b) Available for Limited Use Only NASA ENVIRONMENTAL PROGRAM

Q.C. Eng. G.C. Murphy Date: 7/26/78

* Fiber Wt. = 7.08 x SP.Gr. of fiber.

** No. specimens in Spec./No. specimens tested.

***

Table XLIII. Q.C. Data Summary - Homogeneous Prepreg. (Specification 4013163-48)
Addendum

Prepreg Lot No. 787 — Date Received 7/13/78

Prepreg Type SP313/T300/S — Fiber Batch No. 4/13/79

Quantity 4.54 kgs (10 lbs) — Resin Batch No. ______

	Vendor	M&PTL	Spec.	Accept	Reject
A. Fiber Data:					
Batch No.	498-2				
Tensile Str., MPa (ksi), Avg.	2951(428)	--	410 Min.	x	
Tensile Mod., GPa (msi), Avg.	228(33.0)	--	29 - 34	x	
Density, gms/cc, Avg.	1.719	--	1.785 - 1.827		
B. Prepreg Data:					
Graphite, gms/m2 (gms/ft2) Avg	102(9.5)	104(9.64)	110±4(10.2±0.4)*		x
Individ. Specimens***	--	1/3	2/3		x
Sec Fiber, gms/m2 (gms/ft2)	38(3.5)	36(3.38)	38±3(3.5±0.3)**	x	
Indiv. Specimens***	--	1/3	2/3		x
Tot. fiber wt. gms/m2 (gms/ft2) Avg		140(13.02)	147±4(13.7±0.4)		x
Individual Specimens	--	0/3	2/3		
Resin, gms/m2 (gms/ft2) Avg.	85(7.9)	78(7.2)	79±5(7.3±0.5)	x	
Individual Specimens***	--	3/3	2/3		
Vols., % Wt., Avg. 383 K	0.5	0.24	2% Max.	x	
Indiv. Specimens***	--	3/3	2/3	x	
Gel Time, Mins. 383 K (230° F)	--	50 [2]	40 Min.		x
Flow, % 383 K (230° F)	--	--	3 - 7		
Visual Discrepancies					
C. Laminate Data					
Roll No.(s)		No. 1			
Gel Time in Die, Mins.		50@149°C(300° F)			
Thickness, cm (in.)	0.2(0.080)	0.2(0.080)	0.2 ± 0.005(0.080±0.002)		
Flex. Str. @RT., MPa (ksi)	1634(237)	1634(237)	1345(195)	x	
@394 K (250° F), MPa (ksi)	1310(190)[1]	1496(217)	1172(170)	x	
Flex. Mod. @RT, GPa (msi)	108(15.7)	108(15.7)	97(14.0)	x	
@394 K (250° F), GPa (msi)	107(15.5)[1]	108(15.73)	90(13.0)	x	
SBS Str @RT, MPa (ksi)	87(12.6)	87(12.63)	97(14.0)		x
@394 K (250° F), MPa (ksi)	49(7.1) [1]	70(10.14)	59(8.5)	x	
Fiber Volume, %	--	45.3/11.8	48/12 (60±2)		x
Resin Content, % Wt.	--	32.84	Report		
Voids, %	--	+1.09	2% Max	x	
Density, gms/cc	1.58	1.61	Report		
Cured Thickness per ply - mm (mils)	0.14(5.0)	0.14 (5.0)			

D. Material Disposition

Accept for All Usage ______ Reject __________ and (a) Return to

Vendor ________ or (b) Available for Limited Use Only NASA ENVIRONMENTAL PROGRAM

O.C. Eng. G.C. Murphy Date: 7/26/78

* Graphite Wt. = 5.66 x Sp.Gr. of fiber.
** Sec. Fiber Wt. = 1.42 x Sp. Gr. of fiber.
*** No. Specimens in Spec./No. Specimens tested
[1] Tested at 450 K (350° F)
[2] Gel at 422 K (300°F) not indicative of laminate

Table XLIV. Q.C. Data Summary - Homogeneous Prepreg. (Specification 4013163-48) Addendum

Prepreg Lot No. C8532	Date Received 7/13/78
Prepreg Type NR150A2/T300/S	Fiber Batch No.________
Quantity 2.22 Kgms (4.9 lbs)	Resin Batch No. E15588-59/E15588-27

A. Fiber Data:	Vendor	M&PTL	Spec.	Accept	Reject
Batch No.	515-2				
Tensile Str., MPa (ksi), Avg	3241(470)	--	410 Min.		
Tensile Mod., GPa (msi), Avg	236(34.2)	--	29 - 34		
Density, gms/cc, Avg.		--	1.785 - 1.827		

B. Prepreg Data;	Vendor	M&PTL	Spec.	Accept	Reject
Graphite, /m^2(gms/ft^2)Avg	109(10.08)	108(10.03)	110±4(10.2±0.4)*	x	
Individ. Specimens***	--	2/4	2/3	x	
SecFiber, gms/m^2(gms/ft^2)Avg	29(2.73)	27(2.481)	38±3(3.5±0.3)**		x
Indiv. Specimens***	--	2/4	2/3	x	
Tot. fiber wt. gms/m^2(gms/ft^2)	138(12.81)	140(13.02)	147±4(13.7±0.4)		x
Individual Specimens		1/4	2/3		x
Resin, gms/m^2(gms/ft^2)Avg.	71(6.6)	78(7.259)	79±5(7.3±0.5)	x	
Individual Specimens***		4/4	2/3	x	
Vols., % Wt., Avg, 383 K	18.5[1]	16.1	2% Max.	x	
Indiv. Specimens***	--	--	2/3		
Gel Time, Mins. 383K(230° F)	2 [2]	--	40 Min.	x	
Flow, % 383 K (230° F) &	--	--	3 - 7		
689 kPa (100 psi)	23.0	--	3 - 7		
Visual Discrepancies					

C. Laminate Data	Vendor	M&PTL	Spec.	Accept	Reject
Roll No.(s)					
Gel Time in Die, Mins.					
Thickness, cm (in.)	0.95(0.077)	1.88(0.074)	0.2 ± 0.005(0.080±0.002)		x
Flex. Str.@RT., MPa (ksi)	1207(175)	1531(222)	1345(195)	x	
@394K (250° F), MPa (ksi)	1048(152)	1338(194)	1172(170)	x	
Flex. Mod.@RT, GPa (msi)	100(14.5)	117(17.0)	97(14.0)	x	
@394K (250° F), GPa (msi)	103(15.0)	119(17.3)	90(13.0)	x	
SBS Str.@RT, MPa (ksi)	98(14.2)	90(13.0)	97(14.0)		x
@394K (250° F), MPa (ksi)	70(10.1)	69(10.0)	59(8.5)	x	
Fiber Volume, %	--	53/11	48/12 (60±2)		
Resin Content, % Wt.	31.9	28.84	Report		
Voids, %	--	2.79	2% Max		x
Density, gms/cc	1.7	1.68	Report		
Cured Thickness per ply - mm (mils).	0.14(5.0)				

D. Material Disposition

Accept for All Usage._______Reject__________and (a) Return to

Vendor_________or (b) Available for Limited Use Only NASA ENVIRONMENTAL PROGRAM

Q.C. Eng. G.C. Murphy Date: 7/26/78

* Graphite Wt. = 5.66 x SP.Gr. of fiber.
** Sec. Fiber Wt. = 1.42 x SP. GR. of fiber.
*** No. Specimens in Spec./No. Specimens tested
[1] Tested at 589 K (600° F)
[2] Gel at 477 K (400° F)

C2

Class B parameters for the preparation of the bonded monotape sheets were 789 K (960° F) at $27.57 \times 10^6 n/m^2$ (4 ksi) pressure. Permissible defect criteria and quality assurance provisions were controlled by GE Specification 4013155-235. The volume percent of boron filament was maintaining at 46 to 47 percent. Filament tensile strengths were of $3.4 \times 10^9 n/m^2$ (500 ksi) determined according to GE specification 4013155-237.

4.3 TEST SPECIMEN FABRICATION

4.3.1 Test Specimen Geometry

Figure 18 shows the specimen geometry used for Task II. This geometry has previously been utilized for testing of boron/aluminum and polymeric materials on NASA Program NAS3-19729. The specimens are a double wedge shape section with a 0.38 cm (0.15 in.) maximum thickness and 1.3 mm (0.05 in.) leading edge. The overall chord of 7.6 cm (3 in.) is designed to be long enough to allow impacts at an incidence angle of 25 degrees.

4.3.2 Fabrication Methods

Two basic ply/material layup designs were used for the manufacture of the specimens. A typical diagramatic layup design, shown in Figure 19 was employed for the hybrid composite simulated airfoil specimens. Figure 20 illustrates the basic layup pattern and interleaving of the metallic foil construction used for the superhybrid specimen designs. Each of the 80 preforms was preassembled in accordance with the appropriate configuration and the weight recorded prior to molding.

- PR288/T300 and PR288/T300/S Specimens

  The following procedure was employed in the molding of the PR288 composite specimens:

  - Mold heated to 383 K ± 2 K (230° F ± 50 F).
  - Load preform and slowly close mold to 10 percent off closure in 3 minutes.
  - Hold for 35 minutes.
  - Maintain 2068 - 5171 kPa (300-750 psi) for 2 hours.
  - Remove part from mold and postcure 4 hours at 408 K (275° F) and 1 hour at 450 K (350° F)

Tables XLV and XLVI list the specimens and the manufacturing data generated for the PR288/T300 and the PR288/T300/S designs respectively.

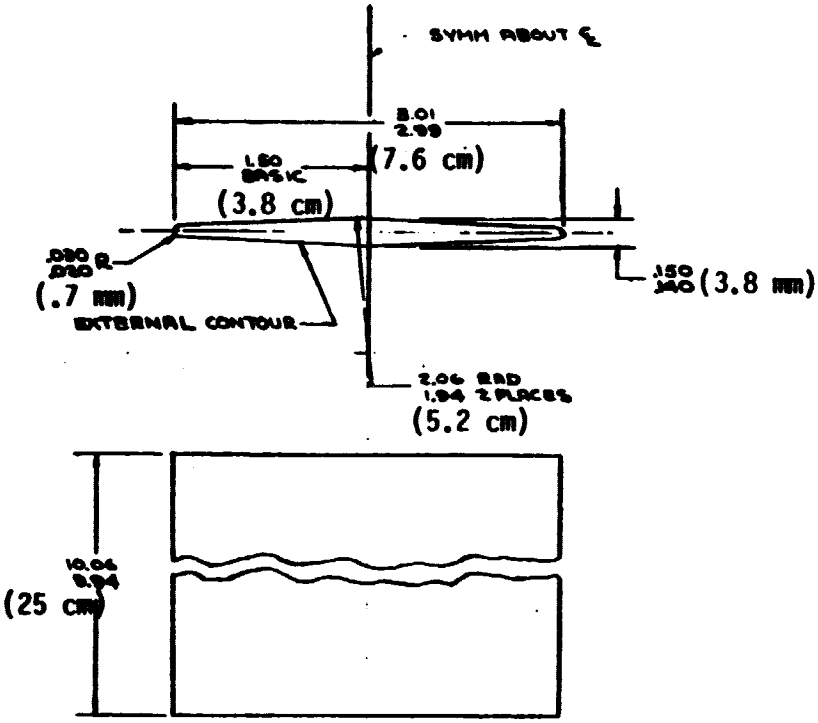
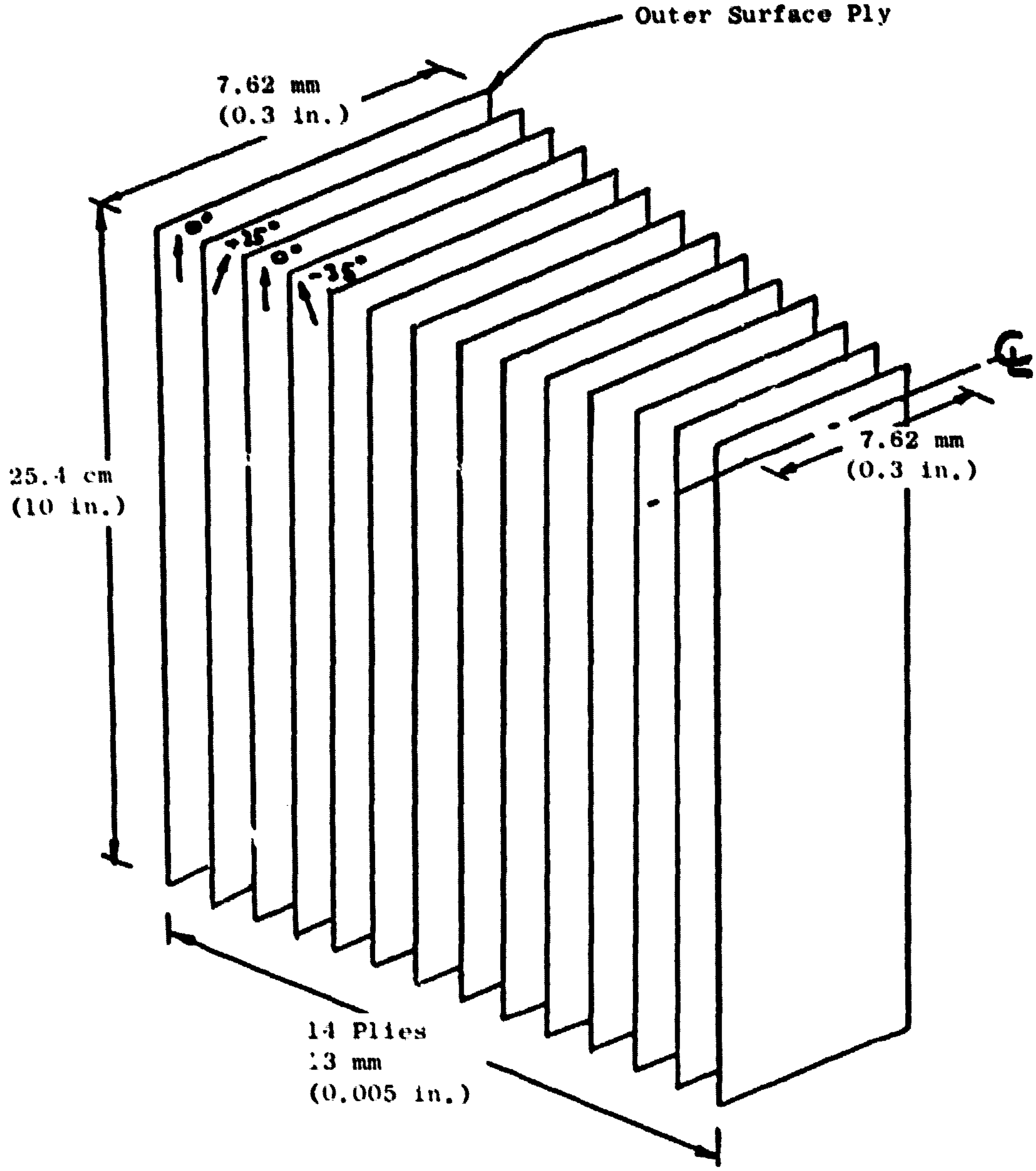


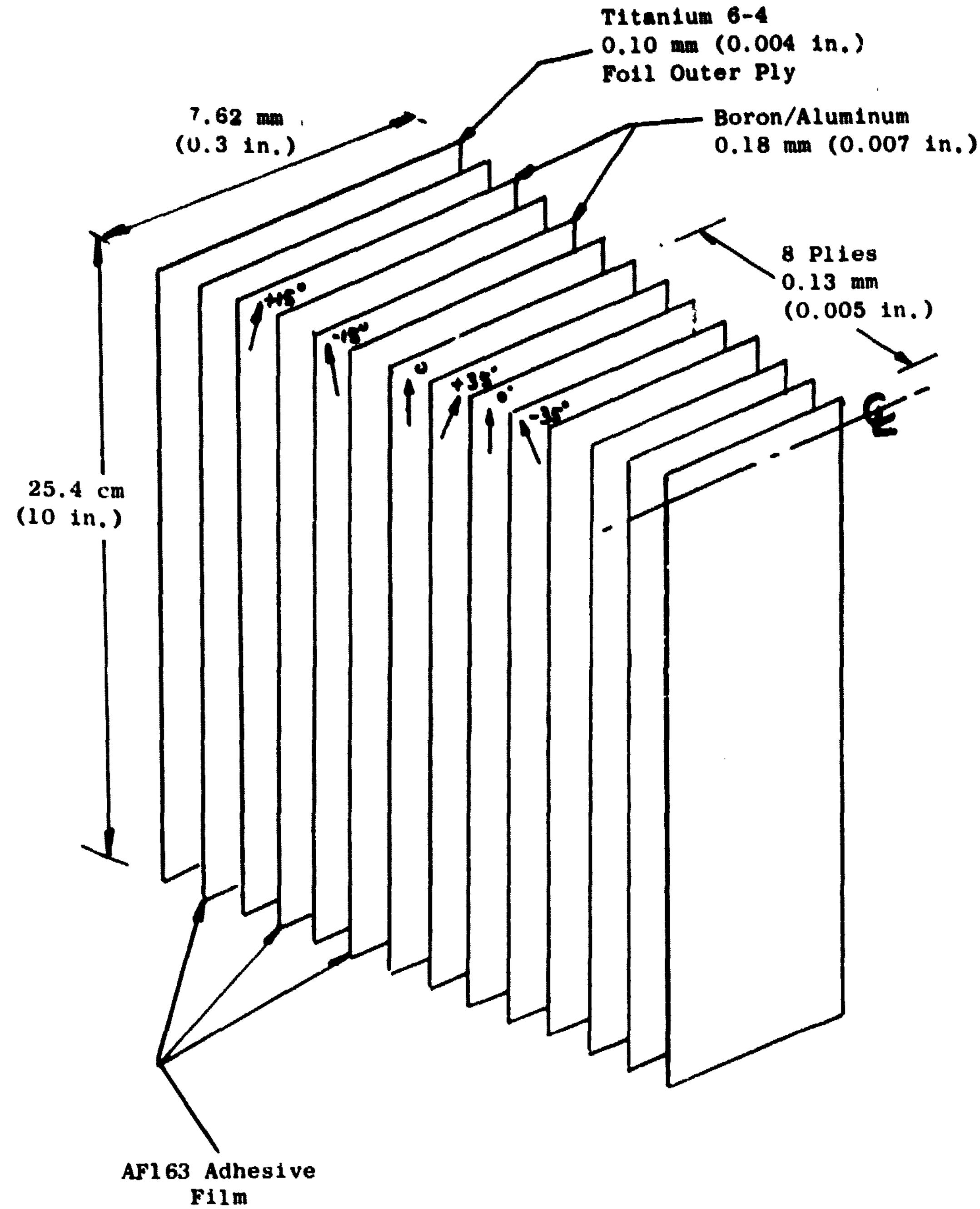
Figure 18. Task II Specimen Geometry.



Basic Layup Patterns 0°, 35°, 0°, -35°

Materials: PR288/T300
PR288/T300/S
SP313/T300/S
NR150A2/T300/S

Figure 19. Typical Layup Pattern for Hybrid Composite Simulated Airfoil Specimens.



Basic Lay-Up Pattern
    Boron-Aluminum +15°, -15°
    Composite Core 0°, 35°, 0°, -35°

Core Materials
    PR288/T300/S
    SP313/T300/S

Adhesive
    AF163

Figure 20. Typical Layup Pattern for Superhybrid Simulated Airfoil Specimens.

Table XLV. Baseline Specimens PR288/T300 Fabrication Data.

Specimen No.	Preform Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
785-1	87	3.86-3.97 (0.152-0.155)	1.520	77.5
785-2	87	3.84-384 (0.151-0.151)	1.529	76.5
785-3	87	3.84-3.81 (0.151-0.150)	1.529	76.5
785-4	88	3.86-3.78 (0.152-0.149)	1.525	77.0
785-5	90	3.89-3.84 (0.153-0.151)	1.520	77.5
785-6	88	3.84-3.86 (0.151-0.152)	1.541	77.0
785-7	89	3.78-3.84 (0.149-0.151)	1.520	76.0
785-8	89	3.78-3.84 (0.149-0.151)	1.524	76.5
785-9	88	3.84-3.89 (0.151-0.153)	1.524	77.0
785-10	89	3.84-3.84 (0.151-0.151)	1.525	77.0
785-11	89	3.86-3.89 (0.152-0.153)	1.535	77.5
785-12	89	3.89-3.86 (0.153-0.152)	1.535	77.5
785-13	88	3.84-3.86 (0.151-0.152)	1.525	77.0
785-14	88	3.89-3.84 (0.153-0.151)	1.540	77.0

Table XLVI. Hybrid PR288/T300/S Specimens Fabrication Data.

Specimen No.	Preform Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
786-1	93	3.75-3.81 (0.148-150)	1.616	80
786-2	93	3.75-3.75 (0.148-0.148)	1.631	80
786-3	93	3.84-3.78 (0.151-0.149)	1.631	80
786-4	93	3.75-3,73 (0.148-0.147)	1.616	80
786-5	93	3.78-3.84 (0.149-0.151)	1.610	80
786-6	93	3.84-3.84 (0.151-0.151)	1.616	80
786-7	93	3.84-3.81 (0.151-0.150)	1.616	80
786-8	93	3.86-3.84 (0.152-0.151)	1.616	80
786-9	93	3.75-3.81 (0.148-0.150)	1.595	79
786-10	93	3.81-3.81 (0.150-0.150)	1.595	79
786-11	93	3.81-3.81 (0.150-0.150)	1.585	79
786-12	93	3.81-3.81 (0.150-0.151)	1.600	80
786-13	93	3.84-3.84 (0.151-0.151)	1.631	80
786-14	93	3.75-3.73 (0.148-0.147)	1.595	79

- <u>SP313/T300/S</u>

  The basic molding procedure developed for the SP313/T300/S composite specimens entailed:

  - Mold heated to 422 K (300° F).
  - Load preform and slowly close mold to 10 percent off closure.
  - Hold for 6-7 minutes.
  - Slowly close mold in 30 minutes.
  - Maintain 2068-5171 kPa (300-750 psi) for 60 minutes.
  - Remove part and postcure 4 hours at 450 K (350° F).

Table XLVII shows the specimens and fabrication data.

- <u>NR150A2/T300/S</u>

  Molding problems associated with specimen surface finish were investigated in conjunction with DuPont (resin manufacturer). Tg (glass transition temperature) evaluation of the specimens indicated that the center section of the "airfoil" specimen to be fully cured and solvent-free showing a Tg value of 548 K (528° F), yet the leading/trailing edges of the specimen had a low Tg value of 407 K (273° F). Insufficient resin matrix was deemed to be the major cause of the poor surface finish and high void content in the specimen. Numerous panels were fabricated varying staging conditions, die closure rates, and modifying the layup to employ a finished 0.114 mm (0.0045) in.) molded thickness per ply compared to the designed 0.127 mm (0.005 in.) to add more material uniformly throughout the preform. During the molding trials it was noted that a considerable amount of solvent and resin was being emitted from the preform during the consolidation/molding cycle from 422 K (300° F) staging temperature to 616 K (650° F), especially as the die temperature reached the 525 K-561 K (485-550° F) range. Experiments indicated that only four percent of the initial sixteen percent was removed during the initial 422 K (300° F) staging. Ten percent was removed during the initial 616 K (650° F) press cure and two percent finally was removed during the "PreDot" final consolidation process at 672 K (750° F). Extended staging times were evaluated between 422 K (300° F) and 616 K (650° F) to allow the solvent to escape slowly from the preform without losing resin matrix. a free oven staging of the preform from room temperature rising a 1.7 K (3° F) per minute to 616 K (650° F) was finally developed which allowed the volatiles to freely and slowly escape.

Table XLVII. Hybrid
SP 313/T300/S Specimens
Fabrication Data.

Specimen No.	Preform Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
787-1	91	3.75-3.81 (0.148-150)	1.554	78.5
787-2	90	3.75-3.78 (0.148-0.149)	1.564	79.0
787-3	90	3.78-3.78 (0.149-0.149)	1.580	79.0
787-4	90	3.75-3,78 (0.148-0.149)	1.580	79.0
787-5	91	3.78-3.78 (0.149-0.149)	1.550	78.0
787-6	91	3.75-3.78 (0.148-0.149)	1.576	78.0
787-7	90	3.81-3.75 (0.150-0.148)	1.579	78.5
787-8	90	3.75-3.81 (0.148-0.150)	1.554	78.5
787-9	90	3.78-3.75 (0.149-0.148)	1.576	78.0
787-10	91	3.81-3.75 (0.150-0.149)	1.550	78.0
787-11A	93	3.91-3.84 (0.154-0.151)	1.558	81.0
787-12	91	3.78-3.81 (0.149-0.150)	1.576	78.0
787-13	90	3.75-3.75 (0.148-0.148)	1.570	78.5
787-14	90	3.78-3.78 (0.149-0.149)	1.550	78.0

The final process developed which produced satisfactory specimen is described below:

- Mold heated to 422 K (300° F).
- Load preform and close mold to 1.65 mm (0.065 in.) off stops.
- Hold for 2 hours.
- Remove consolidate preform and place free in cold oven.
- Raise oven temperature at 1.7 K (3° F) per minute to 616 K (650° F).
- Preform placed back into 422 K (300° F) mold.
- Raise mold temperature at 1.7 K (3° F) per minute to 673 K (750° F).
- Increase molding pressure from 345 kPa to 20,685 kPa (50 psi to 3,000 psi).
- Close mold down to within 0.127 mm (0.005 in.) off closure.
- Release pressure and vent for 30 minutes.
- Reapply 20,685 kPa (3,000 psi) and close mold.
- Hold for 10 minutes.
- Cool to 394 K (250° F) and remove molding.

Table XLVIII lists the NR150A2/T300/S specimens fabricated together with the pertinent manufacturing data.

- <u>Superhybrid PR288/T300/S Specimens</u>

  The superhybrid specimens were fabricated employing 0.1 mm (0.004 in.) titanium 6Al04V foil outer plies and two preconsolidated boron/aluminum foil outer skin plies with a PR288/T300/S composite core. AF163 adhesive was utilized in the foil-to-foil and foil-to-composite interfaces. The pretreatment of the metallic foils involved solvent cleaning, grit blast and priming the surface with XA 3950 primer solution.

  The molding procedure employed involved the following steps:

  - Mold heated to 383 K (230° F).
  - Load preform and close to 5 percent off closure in 5 minutes.
  - Hold for 15 minutes.

Table XLVIII. Hybrid NR150 A2/T300/S Specimen Fabrication Data.

Spec. No.	Preform Weight (grms)	After 422 K (300° F) (grms)	After 616 K (650° F) (grms)	Molded Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
NR1	117	109	100	99	3.73-3.71 (0.147-0.146)	1.692	82.0
NR2	116	109	99	98	3.73-3.71 (0.147-0.146)	1.670	81.0
NR3	117	110	100	99	3.94-3.94 (0.155-0.155)	1.692	88.0
NR4	SCRAP OVER STAGED IN OVEN						
NR5	117	111	100	99	3.91-4.00 (0.154-0.157)	1.695	89.0
NR6	117	110	99	98	3.91-3.86 (0.154-0.152)	1.692	88.0
NR7	116	110	98	97.5	3.96-3.81 (0.156-0.150)	1.684	87.5
NR8	117	111	99	98.5	3.86-3.94 (0.152-0.155)	1.692	88.0
NR9	116	111	99	98	3.91-4.00 (0.154-0.157)	1.692	88.0
NR10	115	110	98	97	3.91-3.90 (0.154-0.153)	1.709	88.0
NR11	115	110	98	97	3.94-3.83 (0.155-0.151)	1.689	87.0

- Slowly close mold applying 517/kPa (750 psi) maximum pressure.

- Maintain temperature and pressure for 2 hours.

- Remove part and postcure for 4 hours at 408 K (275° F) and 1 hour at 450 K (350° F).

Table XLIX lists the manufacturing data associated with the PR288/T300/S superhybrid specimens.

- <u>Superhybrid Specimens SP313/T300/S</u>

  The design of the SP313/T300/S superhybrid specimens was identical with the PR288/T300/S described above with the exception that the metallic foils were primed with EC3917 and AF147 adhesive was employed in lieu of the AF163 system.

  Compatibility studies of the selected AF147 adhesive and the SP313/T300/S prepreg were conducted using the established SP313 molding procedure. Titanium lap shear specimens were fabricated using the AF147 adhesive against the grit blasted and primed titanium blanks with two plies of the SP313/T300/S prepreg sandwiched between. Average lap shear values of 24 MPa (4.07 ksi) were achieved indicating suitable compatibility of the two systems.

  The molding process utilized in the fabrication of the specimens is briefly described below:

  - Mold heated to 422 K (300° F).

  - Load preform and slowly close mold to 10 percent off closure within 5 minutes.

  - Slowly close mold over 15 minutes using 5171 kPa (750 psi) maximum pressure.

  - Maintain temperature/pressure for 60 minutes.

  - Remove part and postcure for 4 hours at 450 K (350° F).

Table L itemizes the specimens fabricated and the fabrication data records.

4.3.3 Nondestructive C-Scan Quality Assurance

All the specimens were inspected by ultrasonic through transmission technique and the resultant C-scans indicated good consolidation with minimum porosity present. An interesting phenomenon was noted during the NDE inspection of

Table XLIX. Superhybrid PR288/T300/S Specimens Fabrication Data.

Specimen No.	Preform Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
PR1	132	3.96-3.94 (0.156-0.155)	2.028	107
PR2	133	3.81-3.81 (0.150-0.150)	2.020	103
PR3	133	3.81-3.90 (0.150-0.153)	1.981	103
PR4	132	3.81-3.78 (0.150-0.149)	2.010	102
PR5	132	3.78-3.81 (0.149-0.150)	1.971	102
PR6	132	3.84-3.86 (0.151-0.152)	1.981	103
PR7	133	3.84-3.84 (0.151-0.151)	1.981	103
PR8	133	3.86-3.78 (0.152-0.149)	1.980	101
PR9	133	3.99-3.84 (0.157-0.151)	1.981	102
PR10	132	3.84-3.84 (0.151-0.151)	1.971	101
PR11	133	3.84-3.86 (0.155-0.152)	1.971	101
PR12	133	3.81-3.86 (0.150-0.152)	1.962	102
PR13	133	3.81-3.90 (0.150-0.153)	1.980	101
PR14	132	3.91-3.81 (0.154-0.150)	1.980	101

Table L. Superhybrid SP313/T300/S Specimens Fabrication Data.

Specimen No.	Preform Weight (grms)	Thickness mm (inches)	Density (gms/cc)	Final Weight (grms)
SP 1	143	4.14-4.06 (0.163-0.160)	2.041	100
SP 2	143	3.96-4.01 (0.156-0.158)	1.943	103
SP 3A	143	3.71-3.83 (0.146-0.151)	1.980	101
SP 4	143	3.86-3.81 (0.152-0.150)	1.981	103
SP 5	143	3.99-3.89 (0.157-0.153)	1.944	105
SP 6	143	3.94-3.83 (0.155-0.151)	1.943	103
SP 7	142	3.76-3.89 (0.148-0.153)	1.962	102
SP 8	141	3.81-3.73 (0.150-0.147)	2.000	100
SP 9	143	4.01-3.81 (0.158-0.150)	1.943	103
SP 10	142	3.86-3.94 (0.152-0.155)	1.943	103
SP 11	141	3.94-3.76 (0.155-0.148)	1.962	104
SP 12	143	3.71-3.83 (0.146-0.151)	2.000	102
SP 13	142	4.04-3.78 (0.159-0.149)	1.945	106
SP 14	142	3.71-3.86 (0.154-0.150)	1.990	101

the SP313/T300/S superhybrid specimens. The first prototype specimen molded indicated a high degree of porosity within the laminate and the process was modified to achieve a more compatible resin gel time in the SP313 with the AF147 adhesive. The C-scan of the second specimen indicated considerable improvement had been achieved by the revised processing. A third specimen was then produced using identical procedures to those employed for the second specimen. The C-scan inspection of the specimen showed apparent high degree of porosity existed within the molding. A detailed investigation of the processing parameters, preform weights, etc., revealed no difference between the two moldings. The only visible difference between the two specimens was that the one exhibiting "low porosity" had been lightly polished to remove surface resin which had bled back onto the titanium outer surface whereas the other specimen retained its original grit blast surface finish. The specimen was polished and rescanned. A considerable improvement was noted in the "apparent" porosity level. Generally, it was concluded that at the high sensitivity level setting of the equipment, the ultrasound was attenuated by the grit blasted surface "roughness". Figure 21 shows the dramatic improvement of the C-scan in "apparent" porosity when half of the specimen SP-8 was polished and the other half left in the grit blasted state. As a result of the findings, all the previously inspected PR288/T300/S superhybrid specimens were polished and rescanned and similar improvement were noted in the C-scans.

4.4 SPECIMEN CONDITIONING

Specimens were allocated to specific environmental humidity conditioning and impact temperatures. The specimens were divided into two batches, the first batch being planned to be impacted with RTV foam, projectiles at low velocity [~244 m/sec (~800 ft/sec)] to determine damage threshold level. After damage evaluation, the second batch of specimens were impacted at higher velocities. The two batches of specimens were, therefore, conditioned approximately three weeks apart to achieve uniform exposure. Tables LI and LII list the specimen allocation for batches No. 1 and No. 2 respectively.

The simulated airfoil specimens were moisture conditioned at 355 K (180° F)/ 97% relative humidity to achieve the "dry" and "wet" and "wet spike" moisture levels. Calibration sample specimens of each material/construction were monitored during exposure to determine when full saturation was achieved as shown in Figure 22.

The approximate weight gain saturation levels for the various design specimens were:

PR288/AS/S Control	2.6 percent
PR288/T300 Baseline	3.1 percent
PR288/T300/S Hybrid	2.7 percent
SP313/T300/S Hybrid	1.7 percent
NR150A2/T300/S Hybrid	0.9 percent
PR288/T300/S Superhybrid	0.3 percent
SP313/T300/S Superhybrid	0.2 percent

Figure 21. Effect of Surface Finish of Titanium Outer Skin of NDE C-Scan Interpretation.

Table LI. Task II - Test Matrix/Specimen Allocation Batch No.1 - Specimen Conditioning/Impact Test Temperature Matrix.

Material	219 K (-65° F) "Dry"	294 K (70° F)			394 K (250° F)		
		"Dry"	Wet	Wet Spike	"Dry"	Wet	Wet Spike
PR288/T300	785-1	785-2	785-3	785-4	785-5	785-6	785-7
PR288/T300/S (Hybrid)	786-1	786-2	786-3	786-4	786-5	786-6	786-7
SP313/T300/S (Hybrid)	787-1	787-2	787-3	787-4	787-5	787-6	787-7
NR150A2/T300/S (Hybrid)	NR-1	NR-2	NR-3	-	NR-5	NR-6	-
PR288/T300/S + Ti + B/Al (Superhybrid)	PR-1	PR-2	PR-3	PR-4	PR-5	PR-6	PR-7
SP313/T300/S + Ti + B/Al (Superhybrid)	SP-1	SP-2	SP-3A	SP-4	SP-5	SP-6	SP-7

Table LII. Task II - Test Matrix/Specimen Allocation Batch No. 2 Specimen Conditioning/Impact Test Temperature Matrix.

Material	219 K (-65° F) "Dry"	294 K (70° F)			394 K (250° F)		
		"Dry"	Wet	Wet Spike	"Dry"	Wet	Wet Spike
PR288/T300	785-8	785-9	785-10	785-11	785-12	785-13	785-14
PR288/T300/S (Hybrid)	786-8	786-9	786-10	786-11	786-12	786-13	786-14
SP313/T300/S (Hybrid)	787-8	787-9	787-10	787-11A	787-12	787-13	787-14
NR150A2/T300/S (Hybrid)	NR-7	NR-8	NR-9	NR-3	NR-10	NR-11	NR-5
PR288/T300/S + Ti + B/Al (Superhybrid)	PR-8	PR-9	PR-10	PR-11	PR-12	PR-13	PR-14
SP313/T300/S + Ti + B/Al (Superhybrid)	SP-8	SP-9	SP-10	SP-11	SP-12	SP-13	SP-14

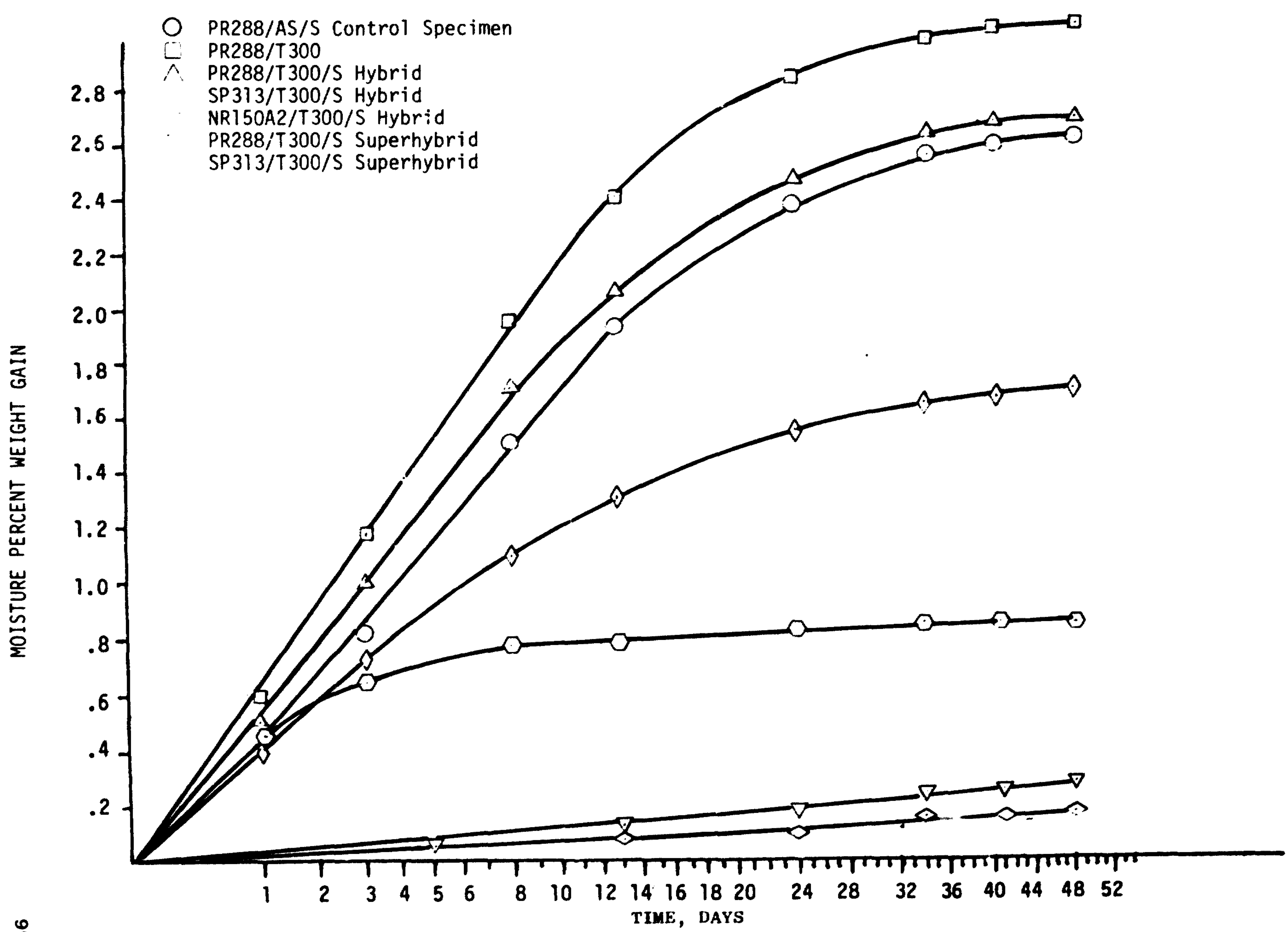


Figure 22. Task II Specimen Moisture Absorption at 355K (180° F)/97 Percent Relative Humidity.

The higher weight percentage gain of the PR288/T300 (3.1%) compared to the hybrid versions PR288/AS/S (2.6%) and PR288/T300/S (2.7%) is a function of the lower density of the material. The actual total weight of absorbed moisture, which is a matrix controlled, for all three materials is almost identical. The superhybrid specimens continued to slowly absorb moisture through the exposed core material at the ends of the specimens. Except for a minor moisture penetration through the leading and trailing edge metallic ply bond lines, the impact zone of the superhybrid specimens were moisture free.

"Dry" specimens were conditioned 36 hours at 355 K (180° F)/97% RH prior to the day of test to achieve the moisture pick-up equivalent to three (3) months ambient storage conditions.

4.5 TORSIONAL TESTING

A Weideman Baldwin torsional fatigue fixture was modified to evaluate the torsional stiffness of the "airfoil" specimens. Clamping fixtures to hold each end of the specimen over 2.54 cm (1 in.) lengths were produced leaving a distance of 20.3 cm (8 in.) between the supports. A 38.73 cm (15.248 in.) radius loading arm was affixed to the free end of the specimen together with a counterbalancing feature to tare-out the loading arm weight. The torsional test apparatus is shown in Figure 23.

Calibration tests were conducted on one specimen of each basic design/ material combinatin to check out the equipment and develop load deflection "curves". Each specimen was torsionally loaded by applying weights to the loading arm and the deflection angle measured by vertical displacement of the loading arm. Typical "dry" specimens from Batch No. 1 were selected for calibration which had not been conditioned but had been stored in ambient room temperature conditions since fabrication. Figure 24 shows the load deflection curves which were developed. After the load was removed, the angle was measured to ensure no permanent deformation after 10 degree twist. All the specimens regained their original shape except for the superhybrid SP313/T300/S specimen (SP-5) which indicated a permanent deformation of ~2 degrees. The specimen was reinspected by ultrasonic C-scan and no internal damage was indicated. The second superhybrid specimen was only calibrated through 5 degrees to prevent similar "damage". Almost identical torsional stiffness characteristics were exhibited by both superhybrid designs (PR-1 and SP-5) and by the epoxy hybrid designs (787-1 and 786-5). The PR288/T300 specimen (785-1) indicates higher torsional stiffness than the hybrid designs which is caused by the inherent higher modulus fiber reinforcement of all T300 and no S-glass. The NR150A2/T300 hybrid specimen (NR-5) indicates a torsional stiffness of ~15 percent than the equivalent epoxy hybrid design specimens reflecting the high transverse flexural properties of the resin as indicated in Task I for 0° orientation NR150A2/ T300 laminates [~83 MPa (~12 ksi)].

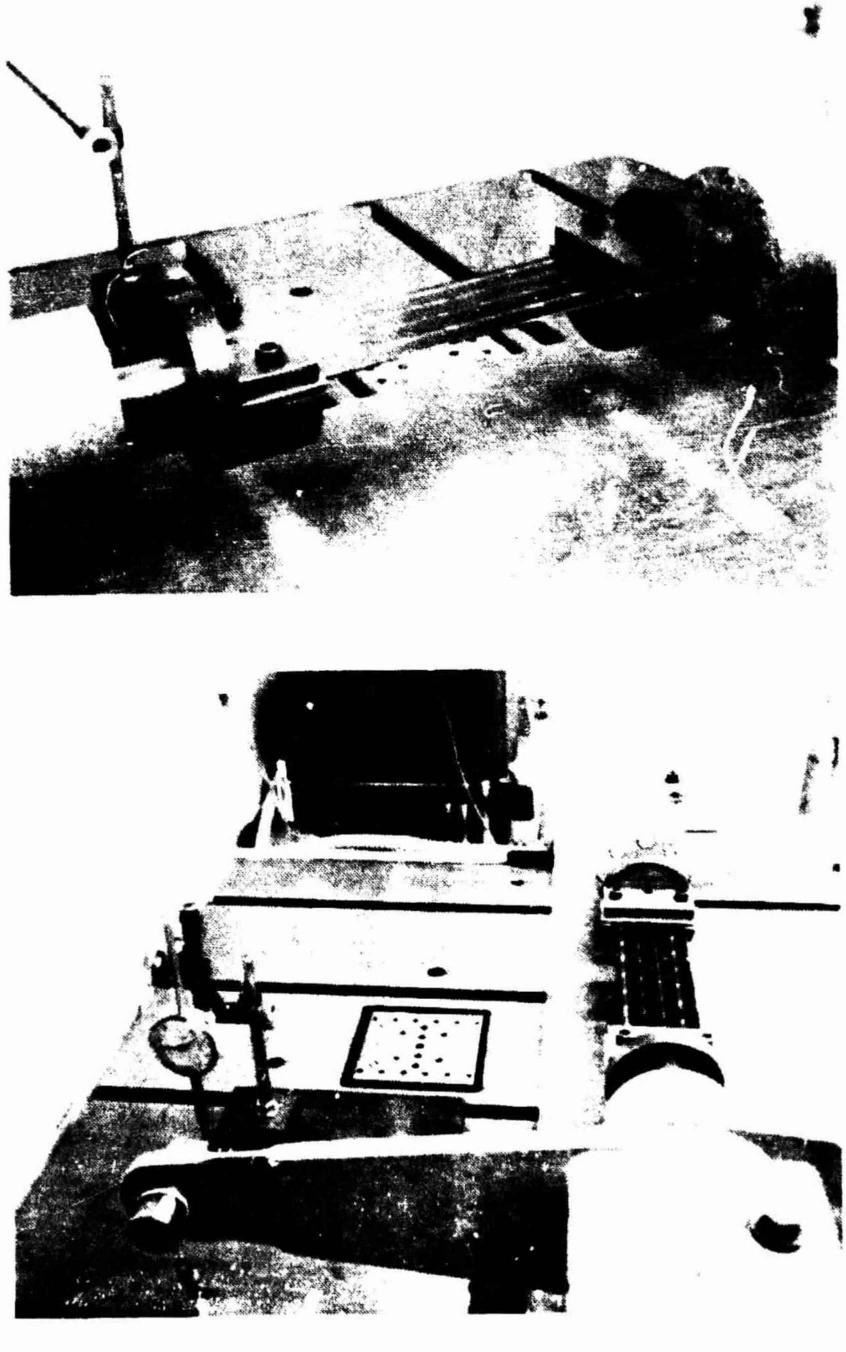


Figure 23. Specimen Torsional Stiffness Measuring Apparatus.

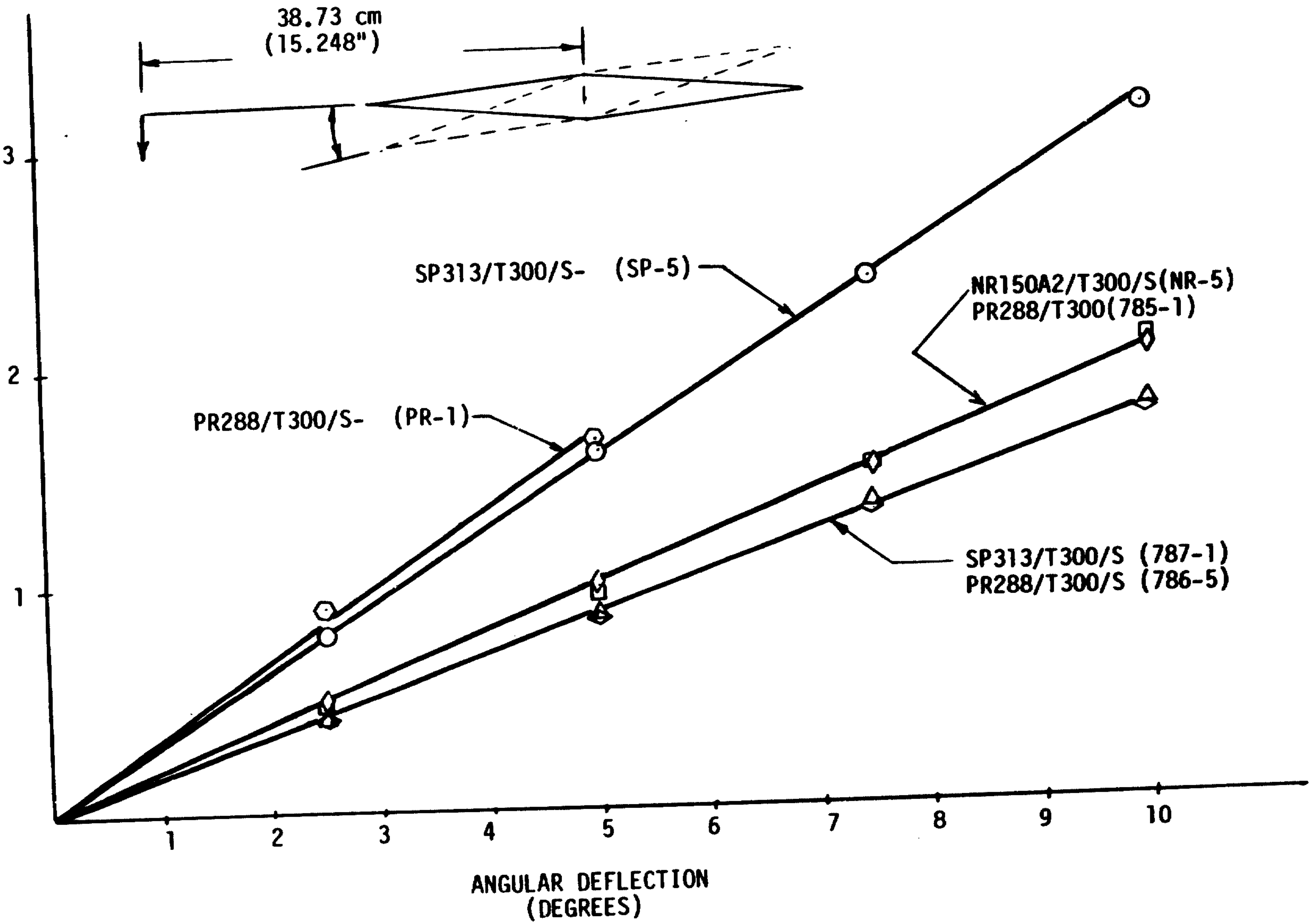


Figure 24. Calibration of Torsional Stiffness Apparatus.

The 294K (70° F) wet spike specimens were initially loaded to achieve 5 degree twist but this degree of torque was diagnosed as being too severe and was believed, together with the thermal spike effect, caused initial damage within the specimens prior to impact. Subsequent specimens were loaded to achieve only 2 degree twist and a procedure of inspecting each specimen by ultrasonic hand scanning was instituted immediately prior to impact to check for any initial damage caused by conditioning or torque testing. Upon completion of the torque test, each specimen was tightly wrapped in aluminum foil to minimize moisture loss and transferred immediately to the University of Dayton for impact testing.

The postimpact test specimens were returned to Cincinnati Testing Laboratory for measurement of the torsional load required to twist the specimens through 2 degrees. It was noted during the repeat torsion testing that some specimens were apparently stiffer after impact. A detailed review of the records indicated that some specimens were retested three days after impact and it was believed that moisture desorption from the specimen was the cause of increase in stiffness. In order to evaluate this phenomenon, the PR288/AS/S "dry" control specimen was removed from the environmental chamber and a daily measurement of moisture content and torsional load required to twist 2 degrees was taken. The results of the study shown in Figure 25 clearly indicate a 0.3 percent change in moisture content, which is primarily surface drying, can effectively change the torsional load by ~3 percent. During the torsion test the repeatability of the test was shown to be within ± 0.5 percent.

4.6 BALLISTIC IMPACT TESTING

4.6.1 Ballistic Impact Test Temperature Calibration

Typical hybrid and superhybrid specimens were supplied to the University of Dayton with thermocouple holes drilled into the core section of each design for temperature surveys to be conducted, in conjunction with the heating/cooling apparatus to establish the parameters prior to commencing impact testing. Additional surface thermocouples were affixed to the surface of the specimen as shown in Figure 26. The specimen was mounted into the clamping fixture and an insulated fiberboard hood ~30 cm (~12 in.) cube was lowered over the whole assembly. Heating was achieved by introducing electrically heated forced air into the chamber and cooling to 219 K (-65° F) by the use of liquid nitrogen.

The resultant heating and cooling cycles to which each particular specimen was subjected is shown on the attached charts. Figure 27 shows the typical heating time for a hybrid specimen and the time of impact after the heating box was removed. Each impacted specimen was fitted with a surface thermocouple S2 to monitor the specimen temperature to determine uniform conditioning at the time of firing the projectile. Figure 28 shows a similar heating calibration curve for a superhybrid design specimen. Figure 29 and 30 show the typical cooling cycle finally developed to achieve semi-uniform temperature thoughout the hybrid and superhybrid specimens respectively using liquid nitrogen as the cooling media.

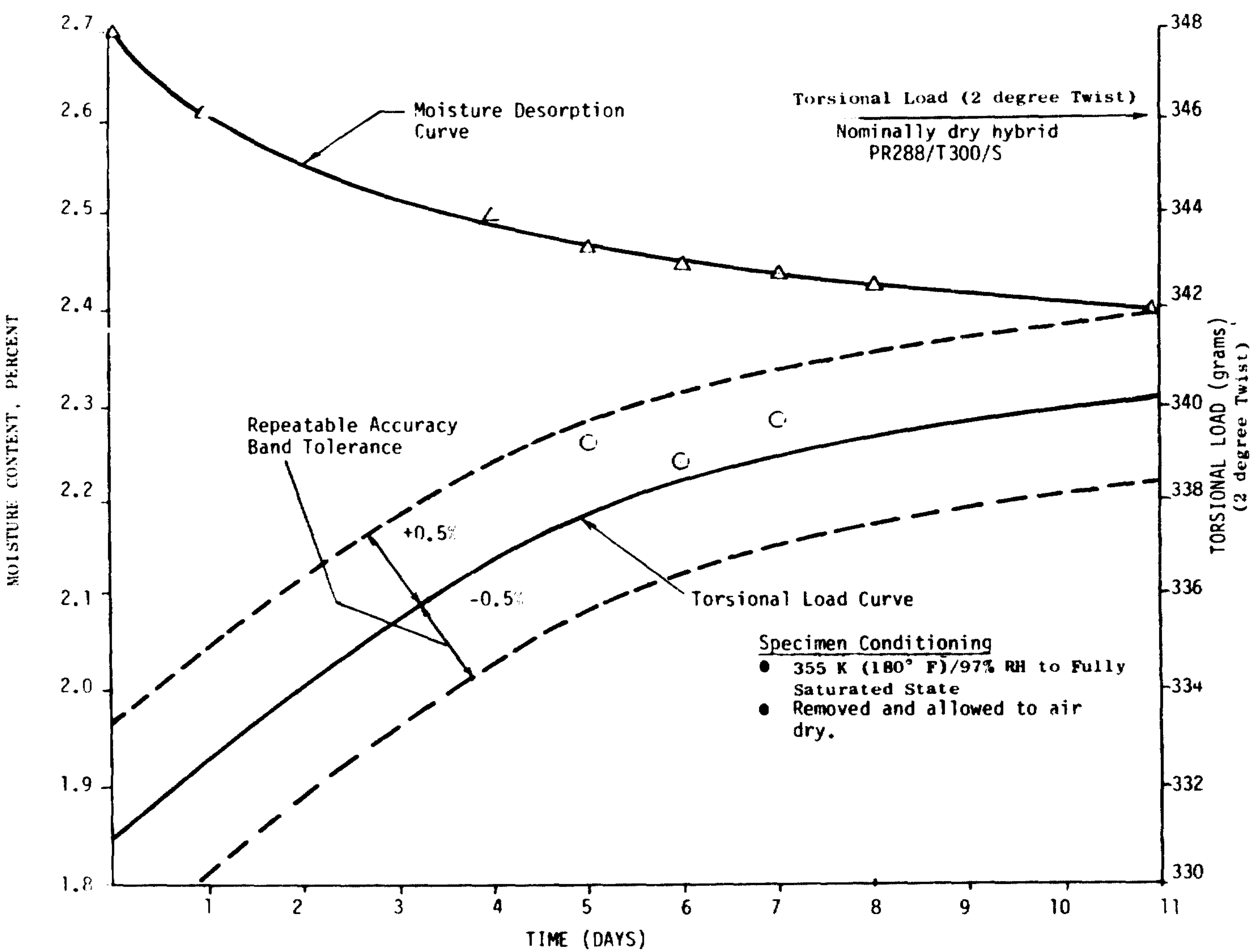


Figure 25. Moisture Desorption and Effect on Torsional Stiffness - PR288/AS/S Calibration Specimen.

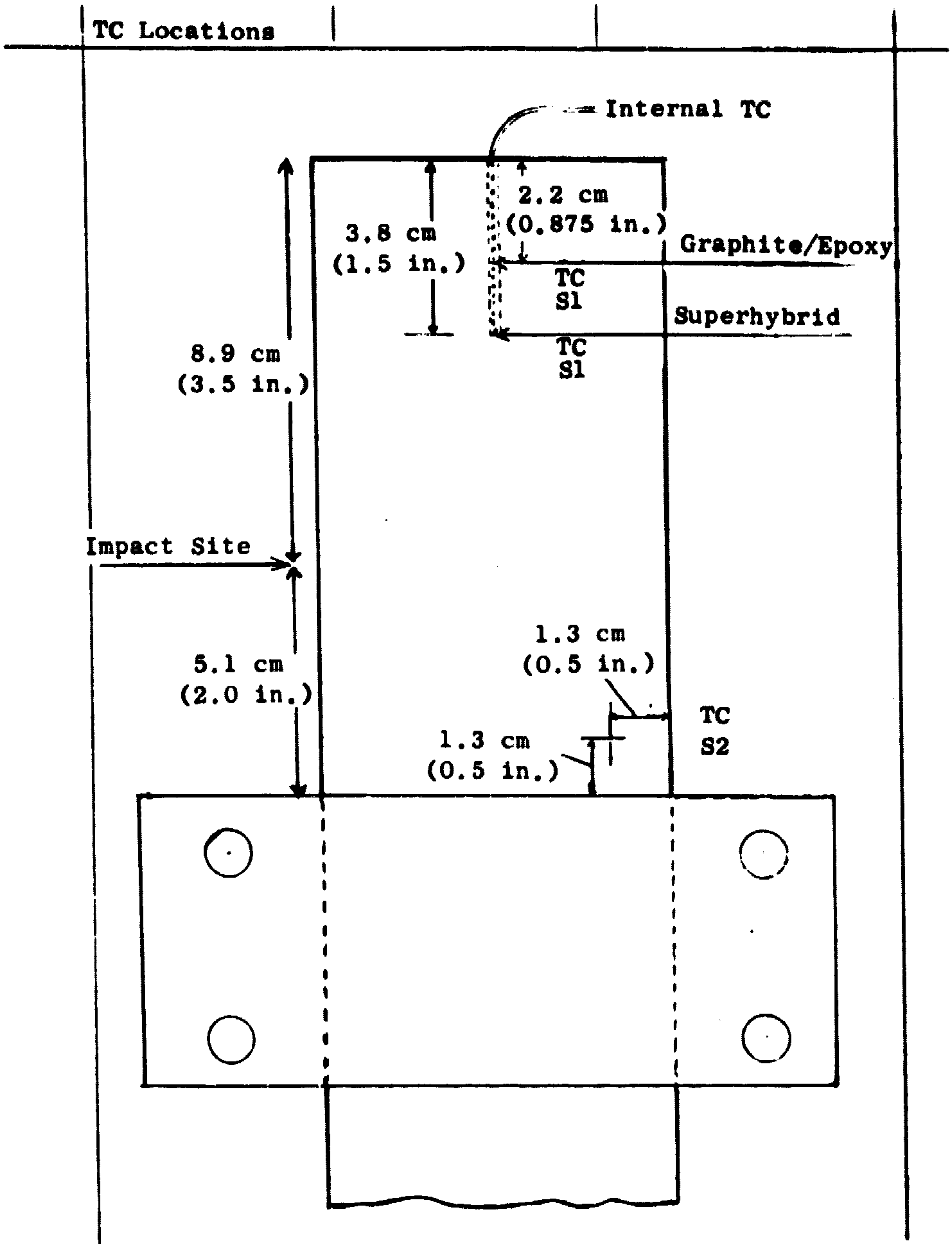


Figure 26. Task II Specimen Support for Impact Testing and Position of Thermocouples Used During Temperature Calibration

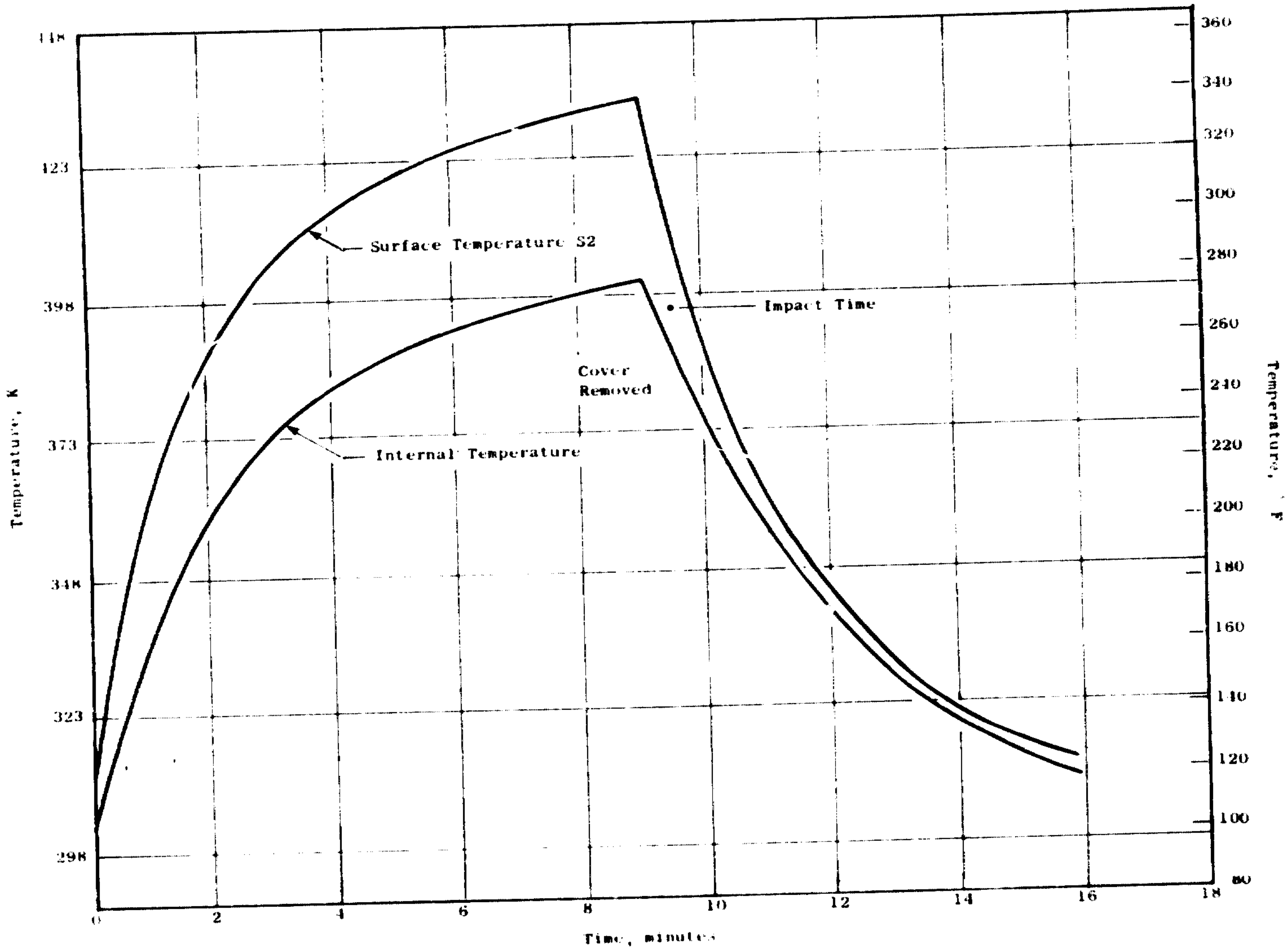


Figure 27. Hybrid Specimen Heating Cycle.

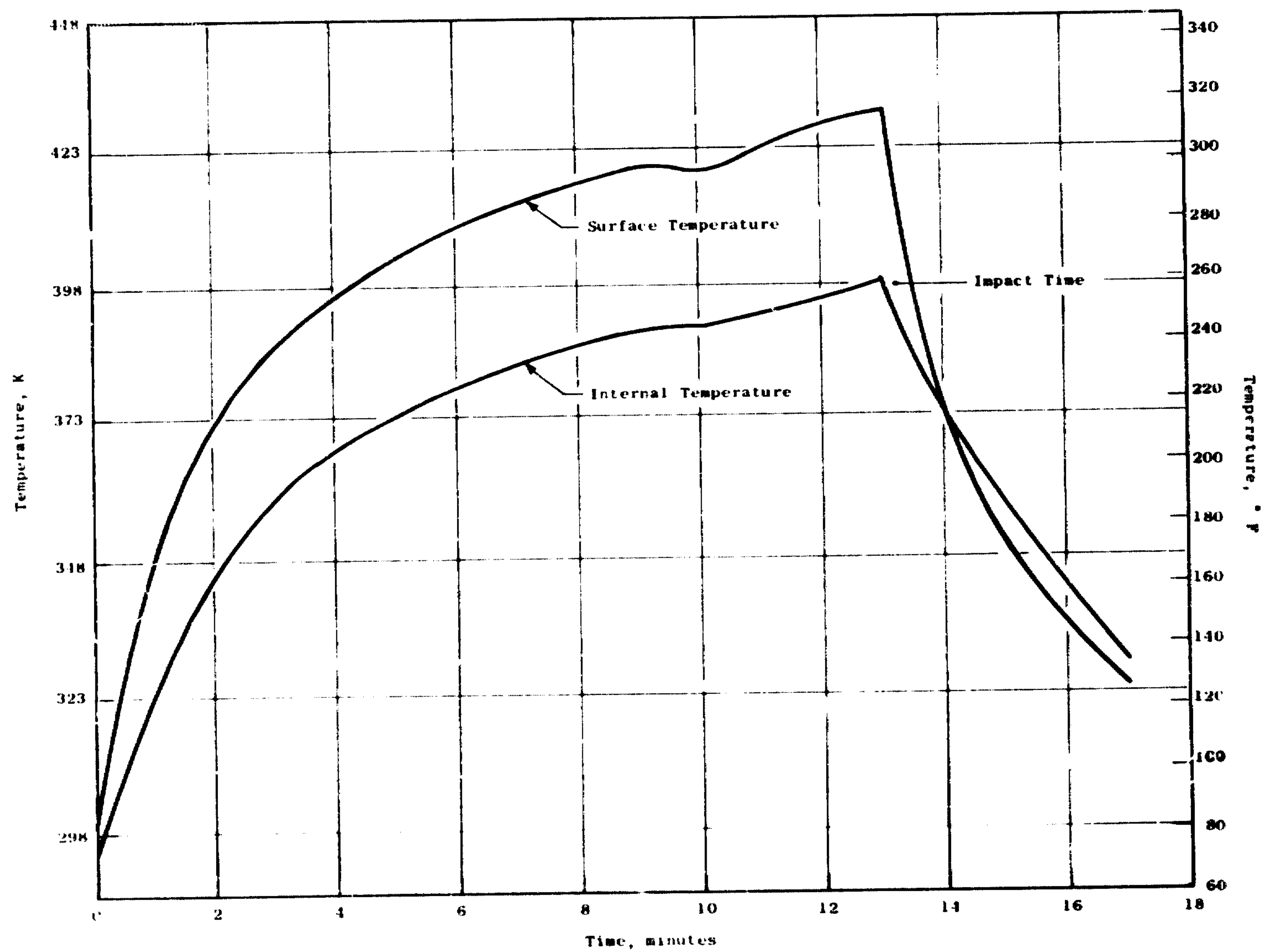


Figure 28. Superhybrid Specimen Heating Cycle.

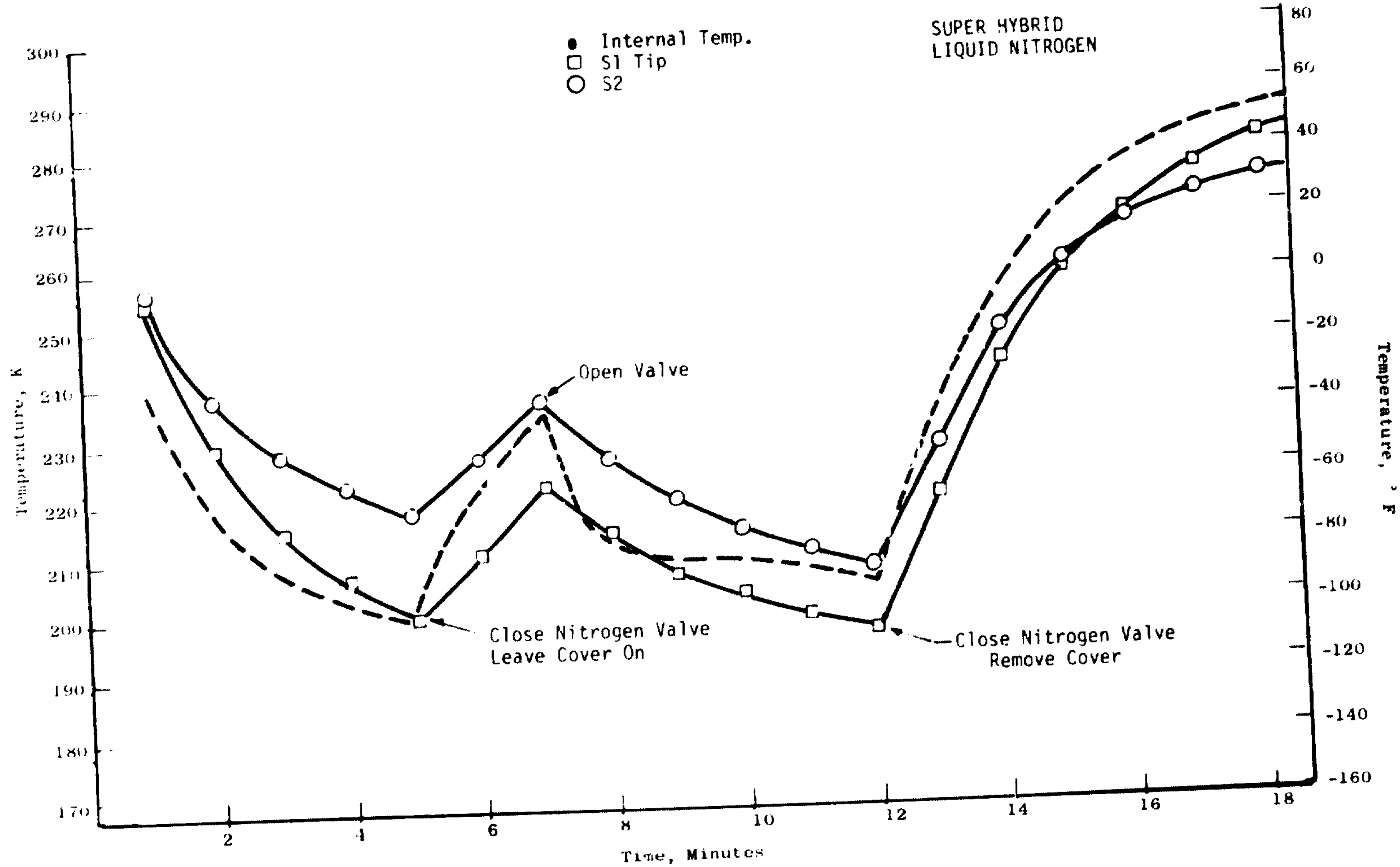


Figure 29. Final Calibration Curve for Low Temperature Shots of Superhybrid Specimens.

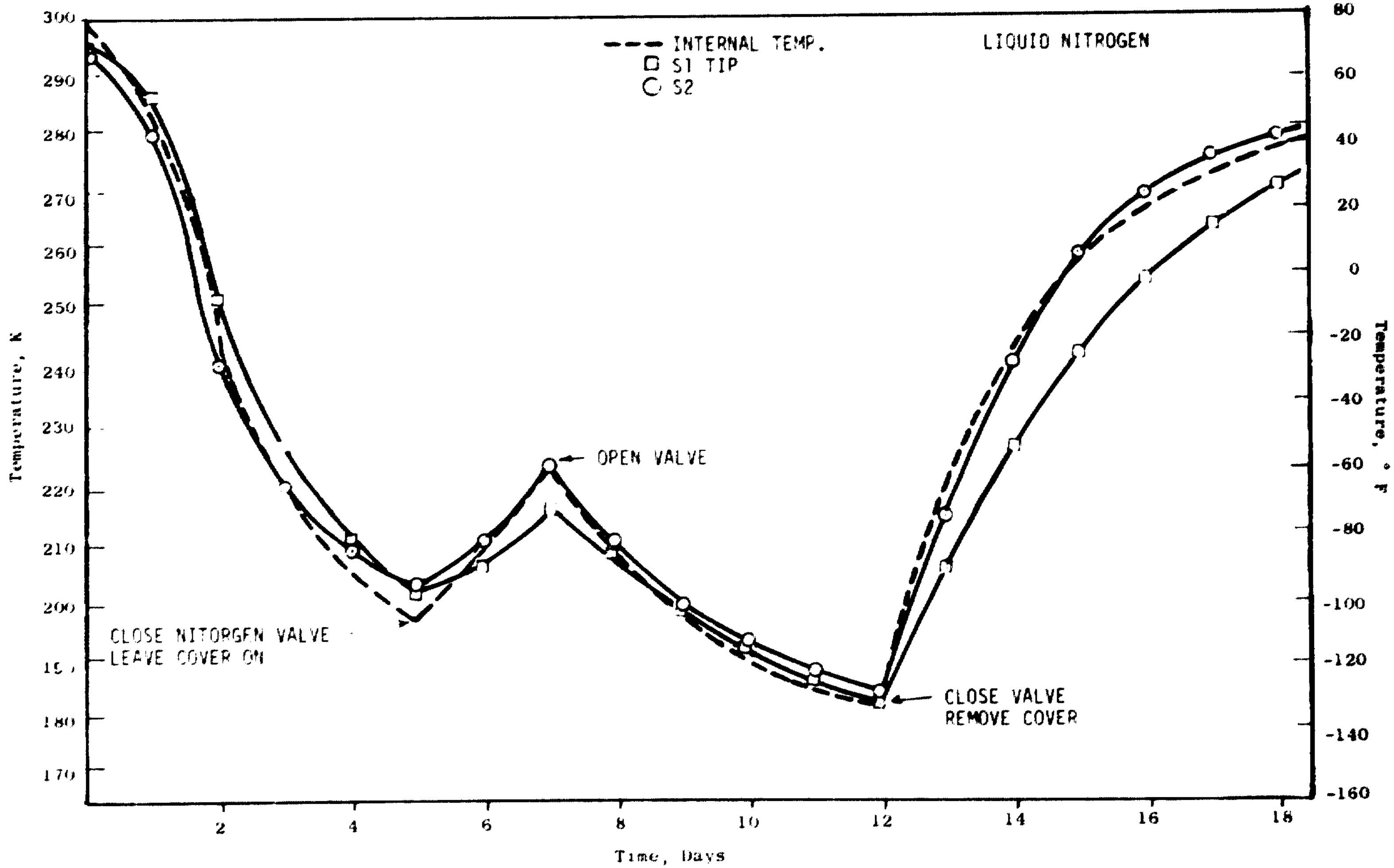


Figure 30. Final Calibration Curves for Low Temperature Shots of Hybrid Specimens.

Due to the use of improper thermocouples during the Batch No. 1 impact tests, the specimens were exposed to inaccurate test temperatures. After the final calibration curves (Figures 29 and 30) were established, it was determined that all the Batch No.1 hybrid type specimens were actually impacted at 209 K (-83° F) rather than 219 K (-65° F) as planned and that the superhybrid specimens were tested at 230 K (-45° F). One Batch No. 2 specimen, S/N 785-14, was also impacted at 419 K (295° F) instead of 394 K (250° F) before the thermocouple problem was discovered.

4.6.2 Ballistic Impact Testing

The Work Statement called for impact testing on a cantilever supported specimen. During testing under NASA Contract NAS3-19729, "Impact Resistant Boron/Aluminum Composites for Large Fan Blades," using cantilever supported specimens of identical geometry most of the specimens suffered "root" bending failures just above the clamp instead of local failures at the point of impact. Since that time General Electric had conducted over 80 ballistic impact tests using a "free-free" configuration where the specimen was not rigidly attached to any support but allowed to move freely after being impacted.

In an attempt to determine a support system which would provide the most meaningful data, several trial impact tests were conducted using prototype specimens supported in the cantilever and free-free mode. The results of these tests are summarized in Table LIII. Eight specimens including four graphite/epoxy (PR288/T300), three hybrid/epoxy and superhybrid/epoxy were used for the tests. The results of this testing indicated that the cantilever test results could be biased by the structural response of the attachment. In all cases, the failure of the cantilever specimens occurred at the clamp either as the sole failure mode or in addition to local damage.

A gelatin projectile of 2.54 cm (1 in.) diameter and 7.7 grams in lieu of the 3.175 cm (1-1/4 in.) dia meter (15 grams) projectile was selected and testing was conducted using a fifty percent slice (2.85 grams) at imapact velocities of 274 m/sec and 304 m/sec (900 and 1000 ft/sec).

Subsequent to this selection, a further specimen was tested using a 5 gram slice of a 15 gram projectile to simulate the revised impact conditions, but at a lower velocity. The results of this test shown in Table LIII, Test No. 2, indicates a combined root and local failure mode.

The Task II Batch No. 1 impact testing was conducted as follows:

- Specimen supported in cantilever mode.
- Specimen was clamped 13.97 cm (5.5 in.) from the free end using a constant clamping load.
- Reusable fiberglass spacers were used between the clamping vise and the specimen.
- Impact location was 5.08 cm (2 in.) up from the clamp (Reference Figure 26).

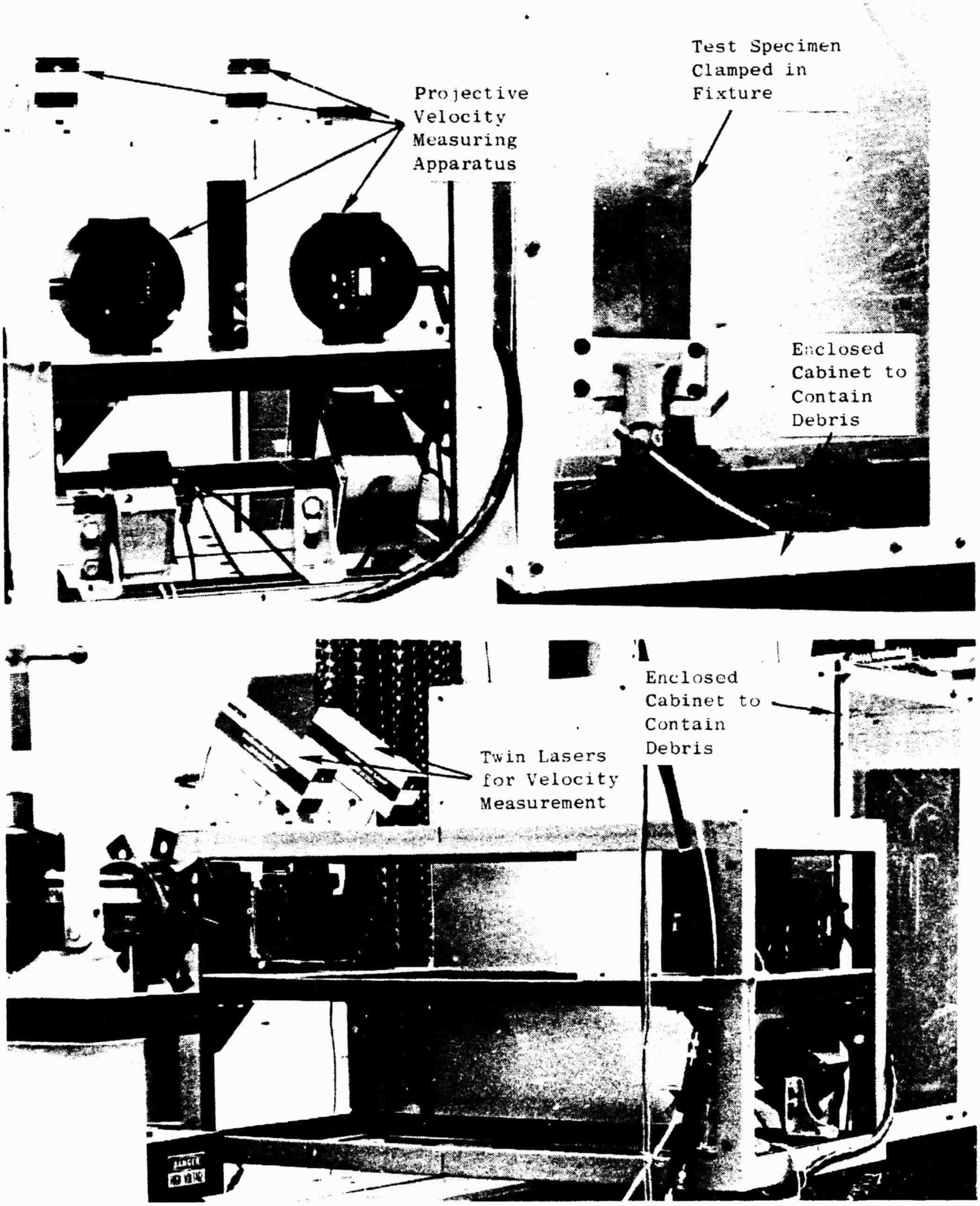


Figure 31. Arrangement of Specimen Ballistic Facility.

Table LIV. Task II Batch No. 1 NDE Specimen Evaluation and Impact Test Data, 219 K (-65° F) "Dry" and 294 K (70° F) "Dry".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation					Impact Data		
			Initial C-Scan Results	Hand Scan Prior to Impact	Hand Scan After Impact	Final C-Scan	Visual Inspection Test	Velocity m/sec (ft/sec)	Slice Size (grams)	Normal Impact Energy Joules (ft-lb)
PR288/T300	785-1	219 K (-65° F) "Dry"	No Indications	No Indications	Delam. 4.84cm^2 (0.74 in.^{2}) Clamp	Delam. 3.2cm^2 (0.5 in^2)	Crack at Clamp	184 (602)	4.804	14.42 (10.64)
PR288/T300/S	786-1	219 K (-65° F) "Dry"	No Indications	No Indications	No Damage	No Damage	Slight Crack at Clamp	188 (615)	4.781	14.98 (11.05)
SP313/T300/S	787-1	219 K (-65° F) "Dry"	No Indications	No Indications	..ight Tip Delam. 3.23cm^2 (0.5 in^2)	Slight Tip Delam. 3.23cm^2 (0.5 in.^{2})	Small Crack at Clamp	191 (625)	2.977	9.63 (7.10)
NR150A2/T300/S (Hybrid)	NR-1	219 K (-65° F) "Dry"	No Indications	No Indications	Delam. Chip Area 3.23cm^2 (0.5 in.^{2}) and Clamp Crack	1.61 cm^2 (0.25 in.^{2}) Delam. Total	Slight Chip L.E. Crack at Clamp	188 (615)	4.857	15.21 (11.22)
(Superhybrid) PR288/T300/S Ti+B/Al	PR-1	219 K (-65° F) "Dry"	No Indications	No Indications	Slight Delam. 0.8cm^2(0.125 in.^{2}) at peel	Slight Delam. 0.8cm^2 (0.125 in.^{2}) at peel	Slight Peel back of L.E.	185 (608)	3.453	10.58 (7.80)
(Superhybrid) SP313/T300/S Ti+B/Al	SP-1	219 K (-65° F) "Dry"	Slight Indications	No Indications	No Damage	No Indications	No Indications	191 (627)	3.265	10.63 (7.84)
PR288/T300	785-2	294 K (70° F) "Dry"	No Indications	No Damage	Clamp Crack	0.65cm^2(0.1 in.^{2}) Delam. Crack Area	Clamp Crack	168 (552)	4.795	12.09 (8.92)
PR288/T300/S	786-2	294 K (70° F) "Dry"	No Indications	No Damage	Clamp Crack	No Damage	Clamp Crack	186 (611)	3.353	10.37 (7.65)
SP313/T300/S	787-2	294 K (70° F) "Dry"	No Indications	No Damage	Clamp Crack and Slight Delam. L.E.	Slight Delam. 1.29cm^2 (0.2 in^2)	Small area missing L.E. Impact area Clamp Crack	183 (599)	4.129	12.27 (9.05)
NR150A2/T300/S (Hybrid)	NR-2	294 K (70° F) "Dry"	3.22cm (0.5 in.) of area indication porosity	No Indications	Surface Delam. 1.29cm^2(0.2 in^2)	Surface Plies Delam L.E. 9.68cm^2+TE 32 26cm^2(1.5 in.^{2}+ TE 5 in.^{2})	T.E. some exploded Surface	193 (632)	2.245	7.43 (5.48)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-2	294 K (70° F) "Dry"	No Indications	No Damage	No Damage	No Damage	No Damage	194 (636)	2.618	8.77 (6.47)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-2	294 K (70° F) "Dry"	Slight Indications (slight porosity)	No Damage	No Damage	No Damage	No Damage	203 (665)	3.335	12.20 (9.0)

Table LV. Task II Batch No. 1 NDE Specimen Evaluation and Impact Test Data, 294 K (70° F) "Wet" and 294 K (70° f) "Wet Spike".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation: Initial C-Scan Results	Hand Scan Prior to Impact	Hand Scan After Impact	Final C-Scan	Visual Inspection Test	Impact Data: Velocity m/sec (ft/sec)	Slice Size (grams)	Normal Impact Energy Joules (ft-lb)
PR288/T300	785-3	294 K (70° F) "Wet"	No Indications	No Damage (Blisters-12)	Clamp Crack	Indications at Clamp	Small Blisters Clamp Crack	120 (392)	7.174	9.13 (6.73)
PR288/T300/S	786-3	294 K (70° F) "Wet"	No Indications	No Damage	No Damage	No Damage	No Damage	193 (633)	2.648	8.79 (6.48)
SP313/T300/S	787-3	294 K (70° F) "Wet"	No Indications	No Damage	0.65cm² (0.1 in²) Delam. area	0.65cm² (0.1 in²) Delam. area	Small TE Split	195 (639)	3.362	11.36 (8.38)
NR150A2/T300/S (Hybrid)	NR-3	294 K (70° F) "Wet"	No Indications	No Damage.	No Damage	No Damage	No Damage	181 (593)	2.943	8.57 (6.32)
(Superhybrid/ PR288/T300/S+ Ti+B/Al	PR-3	294 K (70° F) "Wet"	No Indications	No Damage (Above Clamp)	0.65cm² (0.1 in²) Delam.	0.65cm² (0.1 in²) Delam. LE and TE	Ti peeled 1.94cm² (0.3 in²)	196 (642)	3.192	10.90 (8.04)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-3A	294 K (70° F) "Wet"	No Indications	No Damage	No Damage	0.65cm² (0.1 in²) Indications Clamp Area	No Damage	199 (652)	2.616	9.21 (6.79)
PR288/T300	785-4	294 K (70° F) "Wet Spike"	Small Indications	Not Checked	64.5cm² (10 in²) Delam. Area Clamp	51.6cm² (8 in²) Delam.	Delam/Split L.E. Tip Blisters 50% Area	181 (592)	5.095	14.79 (10.91)
PR288/T300/S	786-4	294 K (70° F) "Wet Spike"	No Indications	Not Checked	100% Delam.	103.22cm² (16 in²) Delam Above Clamp (100%)	Delam. and 12.90 cm² (2 in²)	195 (638)	3.645	12.28 (9.06)
SP313/T300/S	787-4	294 K (70° F) "Wet Spike"	No Indications	Not Checked	100% Delam.	103.22cm2 (16 in²) Delam. above Clamp (100%)	Delam/Blister Over 100% area	206 (677)	5.672	18.98 (14.0)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-4	294 K (70° F) "Wet Spike"	No Indications	Not Checked	96.77cm2 (15 in²) Delam.	96.77cm2 (15 in²) Delam.	Deformed, slight Peeling of Ti	194 (637)	5.584	19.68 (14.51)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-4	294 K (70° F) "Wet Spike"	No Indications	Not Checked	No Damage	No Damage	No Damage	190 (622)	3.611	11.57 (8.53)

Table LVI. Task II Batch No. 1 NDE Specimen Evaluation and Impact Test Data 394 K (250° F) "Dry" and 394 K (250° F) "Wet".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation: Initial C-Scan Results	Nondestructive Evaluation: Hand Scan Prior to Impact	Nondestructive Evaluation: Hand Scan After Impact	Nondestructive Evaluation: Final C-Scan	Nondestructive Evaluation: Visual Inspection Test	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size (grams)	Impact Data: Final Impact Energy Joules (ft/lbs)
PR288/T300	785-5	394 K (250° F) "Dry"	No Indications	No Damage	6.45cm²(1 in.²) Delam. Clamp)	2.5cm²(0.4 in.²) Delam. LE.E.	Crack at Clamp	191 (628)	5.027	16.42 (12.11)
PR288/T300/S	786-5	394 K (250° F) "Dry"	No Indications	No Damage	12.9cm²(2 in.²) Delam. to Clamp	6.45cm²(1 in.2) Delam. Surface Spalling	Crack at Clamp	185 (607)	4.636	14.14 (10.43)
SP313/T300/S	787-5	394 K (250° F) "Dry"	No Indications	No Damage	3.22cm² (0.5 in.²) Delam.	Slight indication at Clamp	Crack at Clamp Only	185 (607)	4.636	9.98 (7.39)
NR150A2/T300/S	NR-5	394 K (250° F) "Dry"	Slight Indication	No Damage	No Damage.	No Damage	No Damage	163 (599)	4.110	12.20 (9.0)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-5	394 K (250° F) "Dry"	No Indications	No Damage	4.84cm²(0.75 in.²) Delam.	3.22cm² (0.75 in²) Delam.	Delam. & Deform. Clamp crack	190 (622)	5.587	17.90 (13.2)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-5	394 K (250° F) "Dry"	No Indications	No Damage	No Damage	Slight indications at L.E.	No Damage	177 (580)	3.4745	9.68 (7.14)
PR288/T300	785-6	394 K (250° F) "Wet"	No Indications	No Damage	No Damage	Slight indications at Clamp	Slight blister & rippling Clamp crack	177 (580)	4.153	11.53 (8.5)
PR288/T300/S	786-6	394 K (250° F) "Wet"	No Indications	No Damage	9.68cm²(1.5 in.²)	Slight indications 0.65cm(0.1 in.²)	No Damage	187 (612)	2.503	7.76 (5.72)
SP313/T300/S	787-6	394 K (250° F) "Wet"	No Indications	No Damage	6.45cm²(1.0 in.²) Delam. Clamp to Impact	Slight indications at Clamp Porosity	Small Cracks above Clamp Surface spalling	[illegible] (583)	4.372	12.31 (9.08)
NR150A2/T300/S (Hybrid)	NR-6	394 K (250° F)	No Indications	No Damage	No Damage	No Damage	No Damage	188 (617)	3.296	10.44 (7.7)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-6	394 K (250° F)	No Indications	12.90cm²(2 in.²) Delam.	35.48cm²(5.5 in.²) Delam. Above Clamp	6.45cm²(1.0 in.²) Delam.	Titanium peeled 6.45cm²(1.0 in.²) Deformed Delam.	185 (605)	4.192	(9.37)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-6	394 K (250° F)	No Indication	No Damage	0.65cm²(0.1 in.²) Delam	0.65cm²(0.1 in.²) Delam. at Impact	Slightly Deformed	191 (627)	3.536	11.51 (8.49)

Table LVII. Task II Batch No. 1 NDE Specimen Evaluation and Impact Test Data, 394 K (250° F) "Wet Spike".

MATERIAL	SPECIMEN S/N	IMPACT TEST TEMP/COND.	NON DESTRUCTIVE EVALUATION					IMPACT DATA		
			INITIAL C-SCAN RESULTS	HAND SCAN PRIOR TO IMPACT	HAND SCAN AFTER IMPACT	FINAL C-SCAN	VISUAL INSPECTION TEST	VELOCITY m/sec (ft/sec)	SLICE SIZE (grams)	NORMAL IMPACT ENERGY Joules (ft/lbs)
PR288/T300	785-7		No Indications	No Damage	14.84cm^2 (2.3 in^2) Delam. Blisters	16.13cm^2 (2.5 Delam.	Large Blisters Ripples & Clamp Crack	184 (603)	3.119	9.40 (6.93)
PR288/T300/S	786-7		No Indications	Questionable TE indications (Torsion test?)	Delam, 25.8cm^2 (4 in^2) T.E. Clamp to Impact	16.13cm^2 (2.5 in^2) Delam. T.E.	Clamp Crack	180 (589)	3.108	8.94 (6.59)
SP313/T300/S	787-7	394 K (250° F) "WET SPIKE"	No Indications	No Damage	14.8cm^2 (2.3 in^2) Delam Clamp to Impact	1.9cm^2 (.3 in^2) Delam.	Clamp Crack Crack & Delam. at Impact area	186 (609)	3.6935 3.6935	11.35 (8.37)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-7		No Indications	Titanium Delam. Torsion Test?	48.38cm^2 (7.5 in^2) Delam. Clamp to Impact	45.16 cm^2 (7.0 Delam. above Clamp	Delam and deformed	186 (609)	5.374	16.52 (12.18)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-7		Very Slight indications	No Damage	No Damage	1.93cm^2 (.3 in^2) Delam. peeled area and at clamp.	3.23cm^2 (.5 in^2) peeled area	188 (617)	5.837	18.40 (13.57)

Table LVIII. Task II Batch No. 1 Specimen Weight Records, 219 K (-65! F) "Dry and 294 K (70° F) "Dry".

MATERIALS	SPECIMEN S/N	IMPACT TEST TEMP/COND.	SPECIMEN CONDITIONED WEIGHTS (grams) FINISHED WEIGHT	WEIGHT PRIOR TO DRYING (CTL)	FULLY DRIED WEIGHT (CTL)	"DRY" WEIGHT	WEIGHT GAIN %	PRIOR TO IMPACT WEIGHT (UDC)	AFTER IMPACT WEIGHT (UDC)	SPECIMEN MAXIMUM THICKNESS mm (inches)	SPECIMEN DENSITY (grams/cc)
PR288/T300	785-1	219 K (-65 F) "DRY"	77.5	78.567	78.421	79.026	.77	79.010	79.022	3.88 (.153)	1.520
PR288/T300	786-1		80.0	81.318	81.192	81.192	.67	81.715	81.721	3.78 (.149)	1.616
SP313/T300/S	787-1		78.5	79.548	79.373	79.825	.57	79.811	79.827	3.78 (.149)	1.554
NR150A2/T300/S (Hybrid)	NR-1		82.0	83.005	83.898	83.315	.50	83.286	83.286	3.73 (.147)	1.692
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-1		107.0	107.850	107.826	107.880	.05	107.877	107.902	3.81 (.150)	2.020
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-1		109.0	109.492	109.468	109.530	.06	109.530	109.547	4.09 (.161)	2.041
PR288/T300	785-2	294 K (70° F) "DRY"	76.5	78.329	78.182	78.844	.85	78.853	78.850	3.83 (.151	1.529
PR288/T300/S	786-2		80.0	81.450	81.320	81.878	.69	81.882	81.880	3.76 (.148)	1.631
SP313/T300/S	787-2		79.0	79.859	79.690	80.095	.51	80.102	80.050	3.76 (.148)	1.564
NR150A2/T300/S (Hybrid)	NR-2		81.0	81.016	80.810	81.435	.77	81.432	81.432	3.73 (.147)	1.670
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-2		103.0	103.712	103.692	103.756	.06	103.760	103.760	3.81 (.150)	2.020
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-2		102.0	105.066	105.045	105.107	.06	105.106	105.106	1.99 (.157)	1.943

Table LIX. Task II Batch No. 1 Specimen Weight Records, 394 K (250° F) "Dry".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights (grams)							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	"Dry Weight	Weight Gain Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-5	394 K (250° F) "Dry"	77.5	79.027	78.894	79.484	0.75	79.485	79.391	3.86 (0.152)	1.520
PR288/T300/S	786-5	394 K (250° F) "Dry"	80.5	81.821	81.688	82.222	0.65	82.227	82.128	3.81 (0.150)	1.610
SP313/T300/S	787-5	394 K (250° F) "Dry"	78.0	79.471	79.297	79.706	0.52	79.714	79.656	3.78 (0.149)	1.550
NR150A2/T300/S (Hybrid)	NR-5	394 K (250° F) "Dry"	89.0	89.841	89.675	90.227	0.62	90.209	90.152	3.89 (0.153)	1.692
PR288/T300/S+ Ti+B/Al (Superhybrid)	PR-5	394 K (250° F) "Dry"	120.0	102.867	102.855	102.898	0.04	102.896	102.881	3.81 (0.150)	1.971
SP313/T300/S+ Ti+B/Al (Superhybrid)	SP-3	394 K (250° F) "Dry"	105.0	105.136	105.123	105.1720	0.05	105.706	104.145	3.94 (0.155)	1.944

Table LX. Task II Batch No. 1 Specimen Weight Records, 294 K (70° F) "Wet" and 394 K (250° F) "Wet".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights (grams)							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	"Dry Weight	Weight Gain Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-3	294 K (70° F) "Wet"	76.5		77.508	79.9305	3.12	79.912	79.911	3.81 (0.150)	1.529
PR288/T300/S	786-3	294 K (70° F) "Wet"	80.0		81.5980	83.5980	2.72	83.583	83.580	3.81 (1.150)	1.631
SP313/T300/S	787-3	294 K (70° F) "Wet"	79.0		79.865	81.2495	1.73	81.235	81.237	3.78 (0.149)	1.580
NR150A2/T300/S (Hybrid)	NR-3	294 K (70° F) "Wet"	88.0		89.106	89.9495	0.94	89.910	89.910	3.94 (0.155)	1.692
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-3	294 K (70° F) "Wet"	103.0		103.400	103.7130	0.3	103.730	103.730	3.83 (0.151)	1.981
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-3A	294 K (70° F) "Wet"	101.0		101.820	101.9840	0.16	102.000	102.000	3.76 (0.148)	1.980
PR288/T300	785-6	394 K (250° F) "Wet"	77.0		78.406	80.902	3.18	80.907	80.757	3.84 (0.151)	1.541
PR288/T300/S	786-6	394 K (250° F) "Wet"	80.0		81.464	83.711	2.75	83.717	83.610	3.84 (1.151)	1.616
SP313/T300/S	787-6	394 K (250° F) "Wet"	78.0		79.280	80.673	1.75	80.679	80.504	3.78 (0.149)	1.576
NR150A2/T300/S (Hybrid)	NR-6	394 K (250° F) "Wet"	88.0		88.423	80.275	0.96	89.251	89.113	3.89 (0.153)	1.692
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-6	394 K (250° F) "Wet"	103.0		103.564	103.897	0.32	103.872	103.827	3.83 (0.151)	1.981
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-6	394 K (250° F) "Wet"	103.0		104.365	104.598	0.22	104.599	104.575	3.89 (0.153)	1.943

Table LXI. Task II Batch No. 1 Specimen Weight Records, 294 K (70° F) "Wet Spike" and 394 K (250° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights (grams)							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	"Wet Weight	After Wet Spike Weight Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-4	294 K (70° F) "Wet Spike"	77.0		77.620	79.770	78.8810 (1.62%)	78.890	78.890	3.81 (0.150)	1.525
PR288/T300/S	786-4	294 K (70° F) "Wet Spike"	80.0		81.414	83.6135	81.9104 (0.61%)	80.228	80.223	3.76 (1.147)	1.616
SP313/T300/S	787-4	294 K (70° F) "Wet Spike"	79.0		79.731	81.1060	80.2188 (0.61%)	80.228	80.228	3.76 (0.148)	1.580
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-4	294 K (70° F) "Wet Spike"	102.0		102.873	103.1715	102.9983 (0.12%)	103.010	103.010	3.81 (0.150)	2.010
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-4	294 K (70° F) "Wet Spike"	103.0		103.173	103.3560	103.3265 (0.15%)	103.334	103.334	3.84 (0.151)	1.981
PR288/T300	785-3	394 K (250° F) "Wet Spike"	76.0		76.926	79.401	79.410 (2.83%)	79.113	78.992	3.81 (0.150)	1.520
PR288/T300/S	786-7	394 K (250° F) "Wet Spike"	80.0		81.350	83.672	83.389 (2.51%)	83.405	83.310	3.81 (1.150)	1.616
SP313/T300/S	787-7	394 K (250° F) "Wet Spike"	78.5		79.431	80.849	80.682 (1.57%)	80.691	80.609	3.78 (0.149)	1.570
(Superhybrid) PR288/T300/S+ Ti+B/Al	SP-7	394 K (250° F) "Wet Spike"	103.0		103.687	103.997	103.908 (0.21%)	103.922	103.872	3.83 (0.150)	1.981
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-7	394 K (250° F) "Wet Spike"	102.0		102.745	102.934	102.909 (0.16%)	102.916	102.888	3.81 (0.150)	2.000

Table LXII. Torsion Load Test Data, 219 K (-65° F) and 294 K (70° F) "Dry".

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-1	219 K (-65° F) "Dry"	400	355.2	269.7	+ 4.08
PR288/T300/S	786-1	219 K (-65° F) "Dry"	354	384.4	329.1	-14.3
SP313/T300/S	787-1	219 K (-65° F) "Dry"	349	327.0	325.9	- 0.2
NR150A2/T300/S (Hybrid)	NR-1	219 K (-65° F) "Dry"	417	315.6	320.7	- 1.6
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-1	219 K (-65° F) "Dry"	655	705.0	741.3	+ 5.1
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-1	219 K (-65° F) "Dry"	624	740.7	748.4	+ 1.04
PR288/T300	785-2	294 K (70° F) "Dry"	400	368.0*	372.3	+ 1.16
PR288/T300/S	786-2	294 K (70° F) "Dry"	354	323.6*	350.6	+ 8.34
SP313/T300/S	787-2	294 K (70° F) "Dry"	349	320.3	351.6	+ 9.8
NR150A2/T300/S (Hybrid)	NR-2	294 K (70° F) "Dry"	417	303.6	304.3	+ 0.23
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-2	294 K (70° F) "Dry"	655	602.8	774.8	+28.5
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-2	294 K (70° F) "Dry"	624	601.2	742.7	+23.5

*Tested to 5 degree twist - Normalized to 2 degree twist.

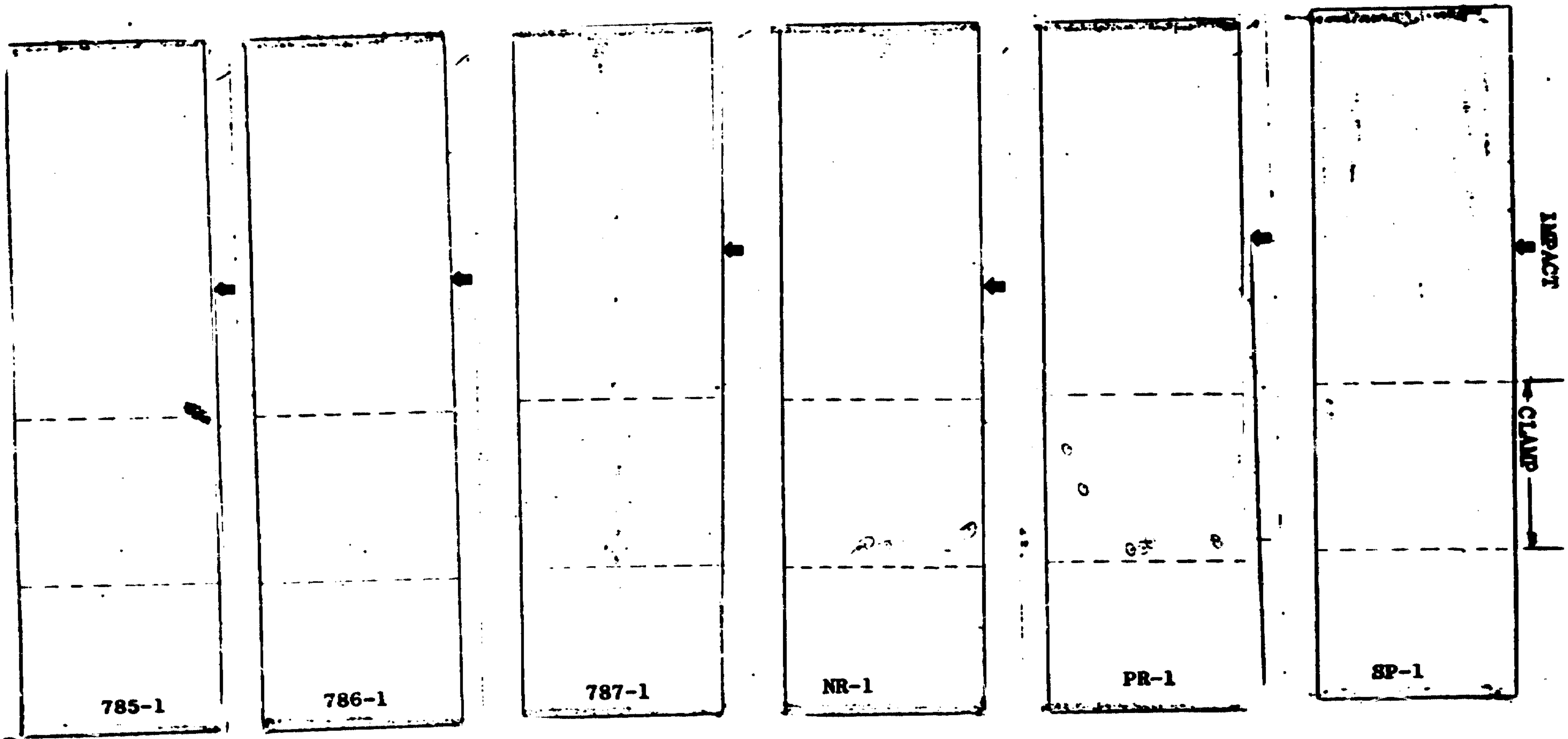


Figure 32. NDE Ultrasonic C-Scan After Impact for 219 K (-65° F) "Dry" Specimens.

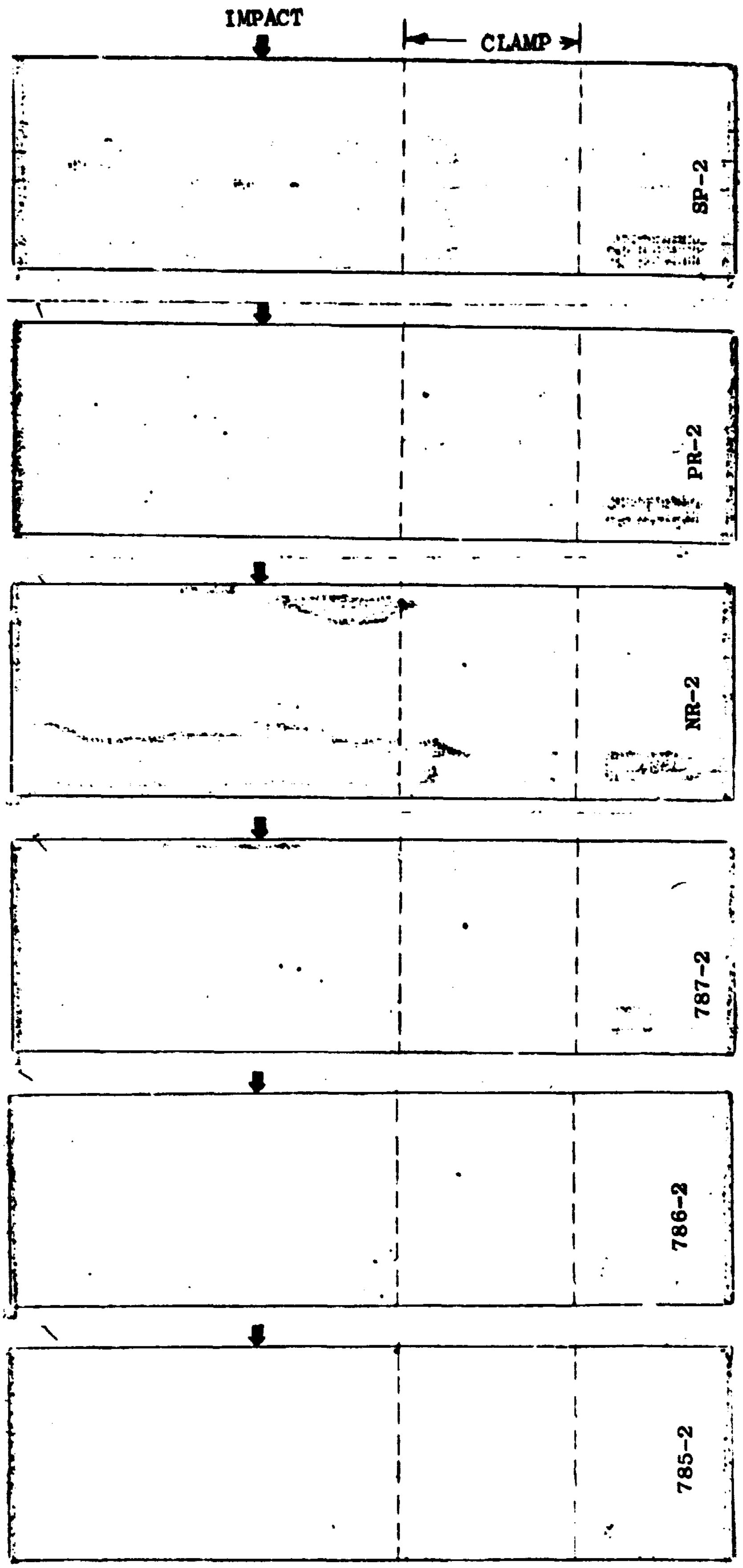


Figure 33. NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Dry" Specimens.

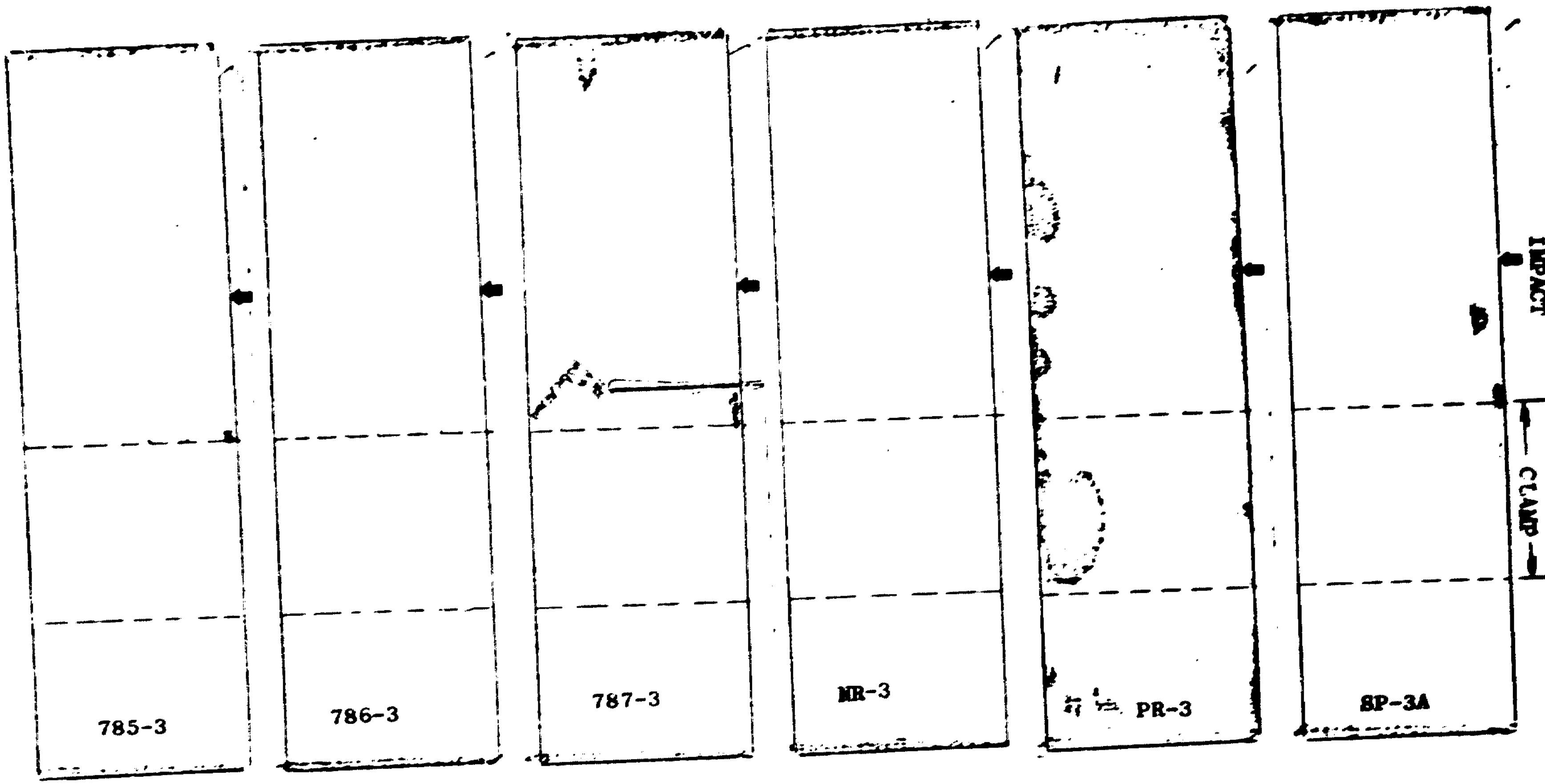


Figure 34. NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Wet" Specimens.

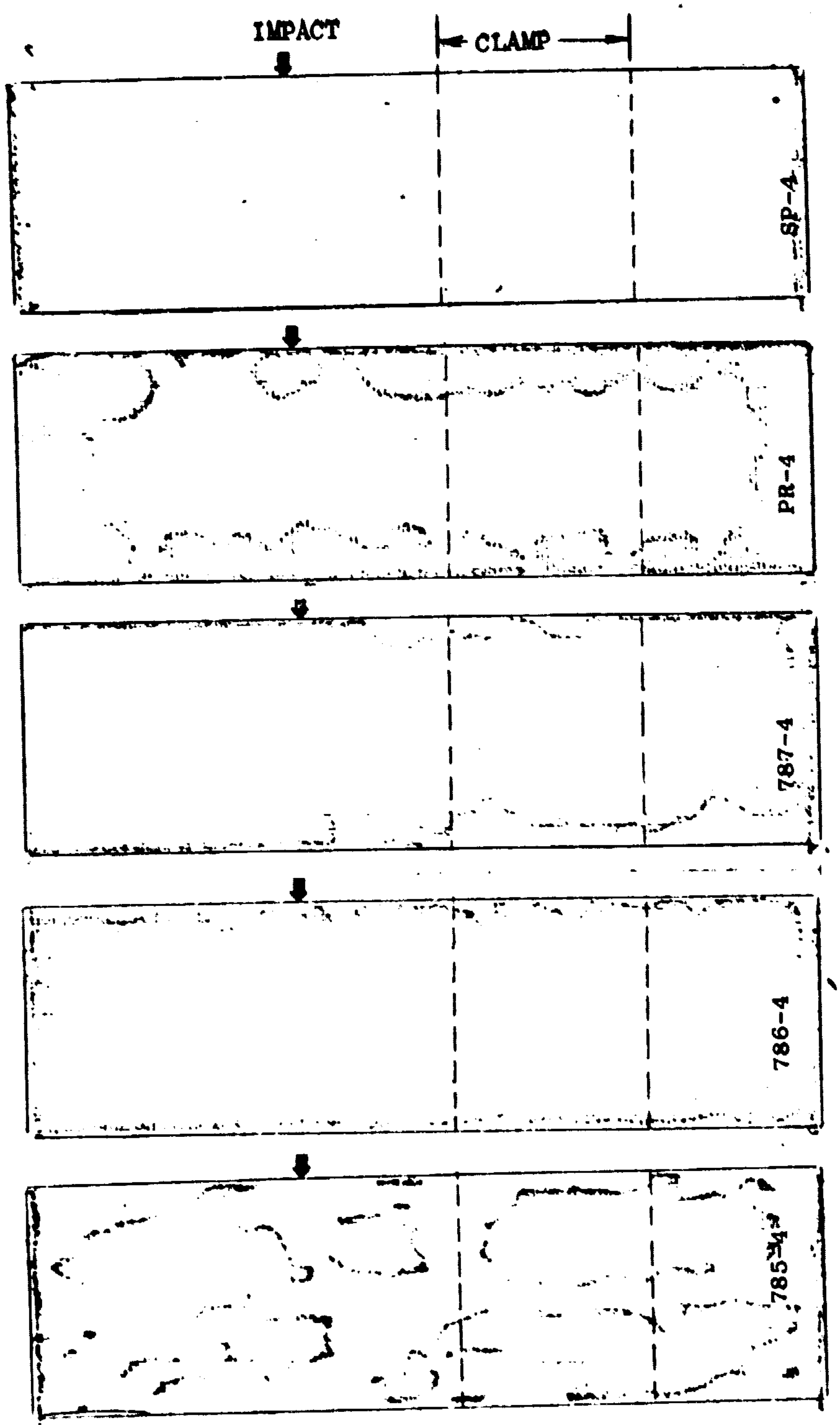


Figure 35. NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Wet Spike" Specimens.

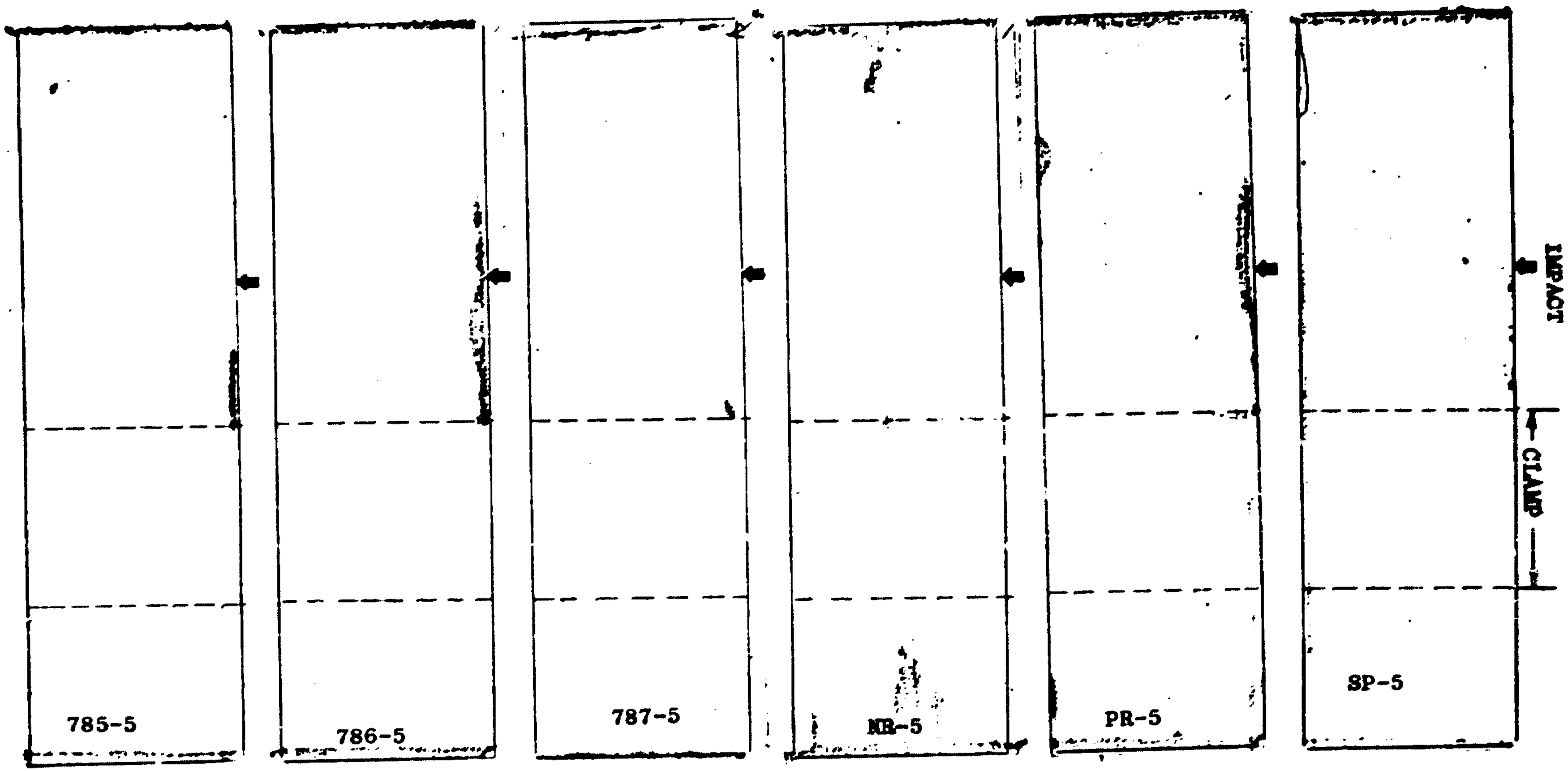


Figure 36. NDE Ultrasonic C-Scan After Impact for 394 K (250° F) "Dry" Specimens.

ORIGINAL PAGE IS
OF POOR QUALITY

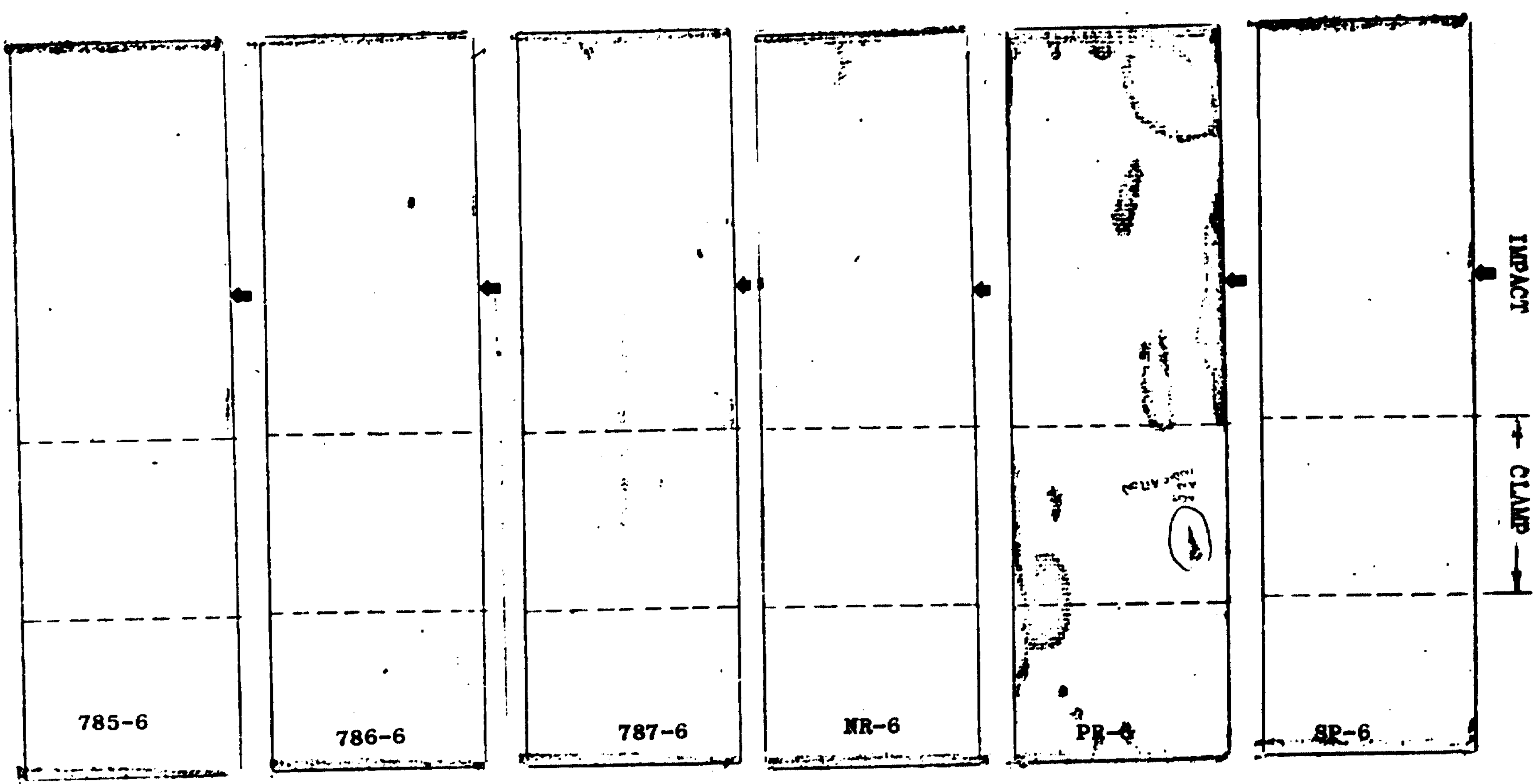


Figure 37. NDE Ultrasonic C-Scan After Impact for 394 K (250° F) "Wet" Specimens.

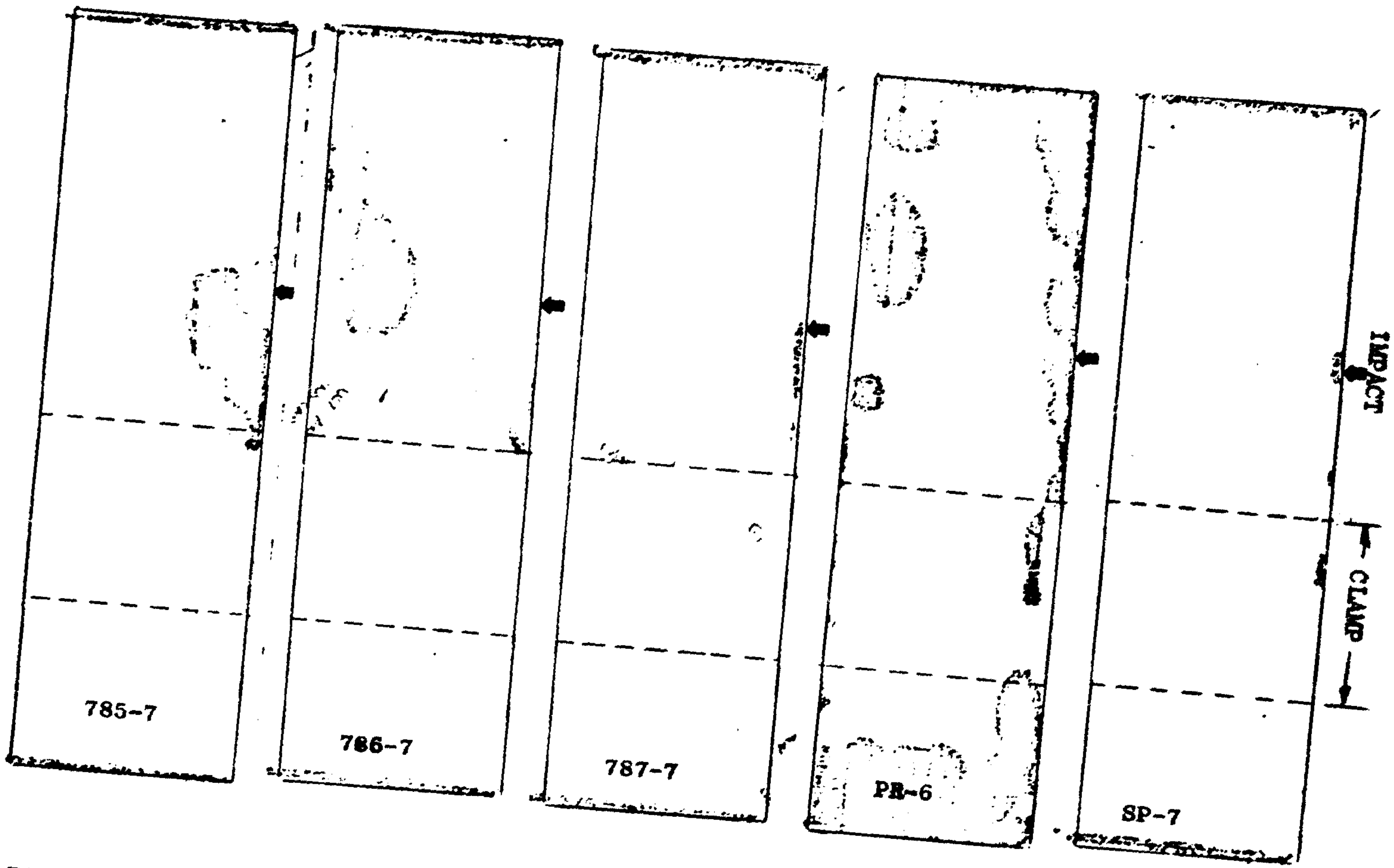


Figure 38. NDE Ultrasonic C-Scan After Impact for 394 K (250° F) "Wet Spike" Specimens.

Table LXIII. Torsion Load Test Data, 294 K (70° F) Wet and 294 K (70° F) Wet Spike.

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-3	294 K (70° F) "Wet"	400	366.7*	373.1	+ 1.7
PR288/T300/S	786-3	294 K (70° F) "Wet"	354	323.5*	331.1	+ 8.6
SP313/T300/S	787-3	294 K (70° F) "Wet"	349	346.4*	351.6	+ 2.3
NR150A2/T300/S (Hybrid)	NR-3	294 K (70° F) "Wet"	417	391.7*	406.7	+ 3.8
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-3	294 K (70° F) "Wet"	655	563.2*	658.8	+16.9
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-3A	294 K (70° F) "Wet"	624	572.4	709.4	+24
PR288/T300	785-4	294 K (70° F) "Wet Spike"	400	349.92*	337.04*	- 3.6
PR288/T300/S	786-4	294 K (70° F) "Wet Spike"	354	336.00*	325.64*	-3.08
SP313/T300/S	787-4	294 K (70° F) "Wet Spike"	349	372.80*	280.40*	-24.9
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-4	294 K (70° F) "Wet Spike"	655	560.40*	599.60*	+7.0
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-4	294 K (70° F) "Wet Spike"	624	591.24*	654.64*	+10.7

*Tested to 5 degree twist - Normalized to 2 degree twist.

Table LXIV. Torsion Load Test Data, 394 K (250° F) Dry and 394 K (250° F) Wet.

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-5	394 K (250° F) "Dry"	400	370.0	390.9	+5.6
PR288/T300/S	786-5	394 K (250° F) "Dry"	354	327.7	380.3	+16
SP313/T300/S	787-5	394 K (250° F) "Dry"	349	335.1	328.8	-1.9
NR150A2/T300/S (Hybrid)	NR-5	394 K (250° F) "Dry"	417	377.0	386.0	+2.4
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-5	394 K (250° F) "Dry"	655	656.6	699.5	+6.53
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-5	394 K (250° F) "Dry"	625	710.0	741.8	+4.5
PR288/T300	786-6	394 K (250° F) "Wet"	400	371.3	369.7	-.4
PR288/T300/S	786-6	394 K (250° F) "Wet	354	279.1	314.9	+12.8
SP313/T300/S	787-6	394 K (250° F) "Wet"	349	345.6	330.5	-4.36
NR150A2/T300/S (Hybrid)	NR-6	394 K (250° F) "Wet"	417	384.9	363.6	- 5.53
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-6	394 K (250° F) "Wet"	655	624.4	716.7	+14.8
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-6	394 K (250° F) "Wet"	625	683.4	649.8	- 4.9

*Tested to 5 degree twist - Normalized to 2 degree twist.

Table LXV. Torsion Load Test Data 394K (250° F) Wet Spike.

Material	Specimen S/N	Impact Test Temp/Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-7	394 K (250° F) Wet Spike	400	358.3	342.7	-4.7
PR288/T300/S	786-7	394 K (250° F) Wet Spike	354	273.0	331.2	+21.3
SP313/T300/S	787-7	394 K (250° F) Wet Spike	349	316.8	332.7	+5.0
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-7	394 K (250° F) Wet Spike	655	663.3	669.2	+0.9
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-7	394 K (250° F) Wet Spike	624	682.0	705.4	+3.4

*Tested to 5 degree twist
Normalized to 2 degree twist

Table LXVI. Batch No. 1 Specimen Ranking by Test.

TEST CONDITION	SPECIMEN DASH NO.	RANKING 1	2	3	4	5	6
219 K (-65° F) "Dry"	-1	SP 786	787	PR	NR	785	
294 K (70° F) "Dry"	-2	SP	PR	786	785	787	NR*
294 K (70° F) "Wet"	-3	NR	787	786	SP	785	PR
294 K (70° F) "Wet Spike"	-4	PR	SP	785	787	786	--
394 K (250° F) "Dry"	-5	NR	787	SP	785	PR	786
394 K (250° F) "Wet"	-6	NR	SP	787	785	PR	786
394 K (250° F) "Wet Spike"	-7	SP	787	786	PR	785	--

* NR Specimen Molding Poor Quality

LEGEND:

785	PR288/T300 (Baseline)
786	PR288/T300/S Hybrid
787	SP313/T300/S Hybrid
NR	NR150A2/T300/S Hybrid
PR	PR288/T300/S+Ti+B/Al Superhybrid
SP	SP313/T300/S+Ti+B/Al Superhybrid

Table LXVII. Batch No. 1 Specimen Design Rating.

Test Condition	Specimen Design Points - Equal Rating					
	785	786	787	NR	PR	SP
219 K (-65° F) "Dry"	5	1	2	4	3	1
294 K (70° F) "Dry"	4	3	5	6*		
294 K (70° F) "Wet"	5	3	2	1	6	4
294 K (70° F) "Wet Spike"	3	5	4	---	1	2
394 K (250° F) "Dry"	4	6	2	1	5	3
394 K (250° F) "Wet"	4	6	3	1	5	2
394 K (250° F) "Wet Spike"	5	3	2	---	4	1
Total Points Actual	30	27	20	13	26	14
Assuming NR Tests 294 K (70° F) & 394 K (250° F) Wet Spike	30	27	20	15	26	14
Ranking Order	6	5	3	2	4	1

*NR Specimen Molding Poor Quality
1-Least Damage
6-Most damage

Legend:

785 PR288/T300 Baseline
786 PR288/T300/S Hybrid
787 SP313/T300/S Hybrid
NR NR150A2/T300/S Hybrid
PR PR288/T300/S+Ti+B/Al Superhybrid
SP SP313/T300/S+Ti+B/Al Superhybrid

Conclusions from the Batch No. 1 specimen impact test are summarized below:

- The Superhybrid design configuration with the more moisture resistant matrix core material (SP313/T300/S) exhibits the best overall resistance to impact damage as shown in Tables LXVI and LXVII (Reference Specimen SP).

- The NR150A2/T300/S hybrid system demonstrated almost equal impact characteristics to the SP313 superhybrid. The superior moisture resistance and improved fracture toughness of the NR150A2 matrix resulted in the best overall impact performance of the specimens (NR) in the wet conditioned state.

- The PR288/T300 (785) nonhybrid "Baseline" system exhibited the worst overall impact resistance characteristics. The poor moisture saturated properties of PR288 resin matrix coupled with the low impact resistance of the pure carbon fiber reinforcement are deemed to be the major contributary causes for the poor impact performance.

- Measurement of torsional stiffness changes in the specimens after impact did not effectively indicate the degree of impact damage. This lack of sensitivity of the test method was partially due to the following conditions:

  - There was no gross damage during the impacting of the specimens and therefore the specimen cross section remained essentially the same except for local delamination

  - Loss of moisture between the time of the impact test and torsion testing resulted in increasing the specimen stiffness as shown in Figure 25.

  - Torsion testing to 5 degree twist caused initial damage to this desin of specimen and 2 degree twist was selected as the test measurement parameter

  - The repeatability of the torsional test data was demonstrated to be within ± 0.5 percent

- There were indications that the thermal spike conditioning at 422 K (300° F) caused some pre-impact damage especially to the moisture saturated lower temperature capability systems.

- The titanium outer layer of the superhybrid systems peeled back in the leading edge impact zone. The low ballistic strain response of the foil bonding adhesives coupled with the degradation of the adhesive caused by moisture ingress between the foils in the leading edge area were the primary cause of this type of failure. A leading edge wraparound protection would eliminate these phenomena.

- An analysis of the impact gun tolerances showed a target accuracy of ± 3.8 mm at 1 m distance (± 0.150 in. at 3 ft) from the gun barrel. The average impact velocity range over the Batch No. 1 tests were 1.68 m/sec to 201 m/sec (552 to 660 ft/sec) the resultant impact energy ranged from 7.4 to 19.7 Joules (5.48 to 14.51 ft-lbs).

- There was no delamination damage on the specimens impacted at 219 K (-65° F) in the dry condition. Three specimens were, however, damaged at the clamp support due to bending and the more brittle nature of the matrices at the cryogenic temperature.

- The cantilever test method obscured the local impact damage results since 20 specimens (50 percent) were damaged at the clamp support due to excessive bending.

4.8 BATCH NO. 2 BALLISTIC IMPACT TESTING

The ballistic impact specimen support method and impact test conditions were modified for the Batch No. 2 specimens after conducting preliminary impact tests, on additional surplus specimens, to ensure minimal root clamp location failures compared to Batch No. 1 where 50 percent of the specimens exhibited local failure in this area.

The final established Batch No. 2 test conditions were:

- Cantilever specimen support (as Batch No. 1).

- Fiberglass spacer clamps protruded ~ 2.3 mm (~ 1/8 in.) above the aluminum clamps.

- 1.5 mm (1/16 in.) rubber pads inserted between the aluminum clamps and the steel vice to help cushion the high stress concentration at the clamp interface.

- Impact velocity increased to 274 m/sec (900 ft/sec).

- Full bite of 2.54 cm (1 in.) diameter gelatin projectile to ensure more uniform impact energy levels.

- Incidence angle 25 degrees.

The revised Batch No. 2 specimen test allocation/conditioning matrix is shown in Table LXVIII. Two undamaged Batch No. 1 NR150A2/T300/S specimens were incorporated into the Batch No. 2 test plan (SN NR-3 and NR-5).

Specimen moisture conditioned weights and the torsion test load data for the specimens are shown in the following tables:

Table LXIX - conditioned specimen weights - 219 K (-65° F) dry and 294 K (70° F) dry

Table LXVIII. Batch No. 2 Specimen Conditioning/Impact Test Temperature Matrix.

Task II - Test Matrix/Specimen Allocation

Material	219 K (-65° F)	294 K (70° F)			394 K (250° F)		
	Dry	Dry	Wet	Wet Spike	Dry	Wet	Wet Spike
PR288/T300	785-8	785-9	785-10	785-11	785-12	785-13	785-14
PR288/T300/S (Hybrid)	786-8	786-9	786-10	786-11	786-12	786-13	786-14
SP313/T300/S (Hybrid)	787-8	787-9	787-10	787-11A	787-12	787-13	787-14
NR150A2/T300/S (Hybrid)	NR-7	NR-8	NR-9	NR-3	NR-10	NR-11	NR-5
PR288/T300/S+ Ti+B/Al (Superhybrid)	PR-8	PR-9	PR-10	PR-11	PR-12	PR-13	PR-14
SP313/T300/S+ Ti+B/Al (Superhybrid)	SP-8	SP-9	SP-10	SP-11	SO-12	SP-13	SP-14

Table LXIX. Task II Batch No. 2 Specimen Weight Records, 219 K (-65° F) and 294 K (70° F) "Dry".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights (grams)							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	Dry Weight	Weight Gain Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-8	219 K (-65° F) "Dry"	76.5	79.0225	77.8601	78.5190	0.85	78.5230	78.4261	3.81 (0.150)	1.524
PR288/T300/S	786-8	219 K (-65° F) "Dry"	80.0	81.4965	81.3510	81.9275	0.71	81.9331	81.9150	3.86 (0.152)	1.616
SP313/T300/S	787-8	219 K (-65° F) "Dry"	78.5	79.6804	79.4900	49.8055	0.51	79.9009	79.8328	3.78 (0.149)	1.48
NR150A2/T300/S (Hybrid)	NR-7	219 K (-65° F) "Dry"	87.5	88.7195	88.4855	89.0360	0.62	89.0222	88.8227	3.89 (0.153)	1.684
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-8	219 K (-65° F) "Dry"	101.0	102.6543	102.6425	102.6830	0.04	102.6908	102.7710	3.84 (0.151)	1.980
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-8	219 K (-65° F) "Dry"	100.0	101.7195	101.7090	101.7393	0.03	101.7444	101.8460	3,78 (0.149)	2.000
PR288/T300	785-9	294 K (70° F) "Dry"	77.0	78.2755	78.1170	78.7425	0.80	78.7445	77.8545	3.86 (0.152)	1.524
PR288/T300/S	786-9	294 K (70° F) "Dry" dry	79.0	80.9300	80.7945	81.3310	0.66	81.3221	89.2829	3.78 (1.149)	1.595
SP313/T300/S	787-9	294 K (70° F) "Dry"	78.5	79.2355	79.0490	79.4500	0.51	79.4446	79.3722	3.78 (0.149)	1.576
NR150A2/T300/S (Hybrid)	NR-8	294 K (70° F) "Dry"	88.0	89.2905	89.0800	89.5980	0.58	89.5684	89.5684	3.89 (0.153)	1.692
(Superhybrid) SP313/T300/S Ti+B/Al	PR-9	294 K (70° F) "Dry"	102.0	103.7925	103.7790	103.8340	0.5	103.8341	103.8376	3.91 (0.154)	1.981
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-9	294 K (70° F) "Dry"	103.0	104.1320	104.1195	104.1610	0.4	104.1707	104.1769	3.91 (0.154)	1.943

Table LXX	- conditioned specimen weights 295 K (70° F) wet and 394 K (250° F) wet
Table LXXI	- conditioned specimen weights 294 K (70° F) and 394 K (250° F) wet spike
Table LXXIl	- conditioned specimen weights 394 K (250° F) dry
Table LXXIII	- torsion load test data 219K (-65° F) and 294 K (70° F) dry
Table LXXIV	- torsion load test data 294 K (70° F) wet and 294 K (70° F) wet spike
Table LXXV	- torsion load test data 394 K (250° F) dry and 394 K (250° F) wet
Table LXXVI	- torsion load test data 394 K (250° F) wet spike

The impacted specimens were reinspected by ultrasonic C-scan and the reduced size copies of the C-scan are shown in Figures 39 through Figure 45.

4.9 DATA EVALUATION RESULTS AND CONCLUSIONS

The Batch No. 2 specimen impact damage assessment conducted using ultrasonic hand scanning and C-scanning methods together with visual inspection and impact test parameters tabulated in Tables LXXVII through LXXX.

The revised specimen clamping support for the Batch No. 2 specimens did partially reduce the susceptability for specimens to fail in bending at the clamp interface. Nineteen percent of the specimens did exhibit localized clamp zone surface cracks.

Several attempts were made to arrange the data in a nondimension form using several variables including normal impact energy, area of delamination, flexural strength, shear strength percent moisture, and test temperature. These attempts were not successful in producing a meaningful correlation of data, therefore, a more straight forward method of presenting the data as a function of percent delamination versus normal impact energy has been used for each of the material combinations and environmental conditions. These results, which proved to be meaningful in evaluating the data, are shown in Figures 47 through 51. Further simplification of this data is shown in Figures 52 and 53 in the form of a bar graph for all of the materials and environmental conditions. The Batch No.1 test results are distinguished from the Batch No. 2 results by cross hatching. Using data from these figures, the materials were ranked using a numerical grading system of 1 through 6 depending on their degree of delamination from the Batch No. 2 test conditions (i.e. 274 m/sec [900 ft/sec] and 25 degrees incidence angle, and 717 gram slice). Table LXXXI presents the summary of this ranking by test and Table LXXXII the rating by specimen design. The observations and conclusions from this data are as follows:

Table LXX. Task II Batch No. 2 Specimen Weight Records, 294 K (70° F) and 394 K (250° F) "Wet".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	Net Weight	Weight Gain Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-10	294 K (70° F) "Wet"	77.0		78.4590	80.9410	3.16	80.9500	80.7478	3.84 (0.151)	1.525
PR288/T300/S	786-10	294 K (70° F) "Wet"	79.0		80.6235	82.8395	2.75	82.8510	82.3855	3.81 (0.150)	1.595
SP313/T300/S	787-10	294 K (70° F) "Wet"	78.0		79.1041	80.6100	1.90	80.6208	80.2745	3.81 (0.150)	1.53
NR150A2/T300/S (Hybrid)	NR-9	294 K (70° F) "Wet"	88.0		89.3920	90.2940	1.01	90.2606	90.1661	3.97 (0.155)	1.692
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR- 10	294 K (70° F) "Wet"	101.0		103.0300	103.5505	0.51	103.5772	103.5800	3.84 (0.151)	1.971
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-10	294 K (70° F) "Wet"	103.0		104.0740	104.3680	0.28	104.3719	104.3773	3.89 (0.153)	1.943
PR288/T300	785-13	394 K (250° F) "Wet"	77.0		78.1485	80.6520	3.20	80.6615	80.5315	3.84 (0.151)	1.525
PR288/T300/S	786-13	394 K (250° F) "Wet"	80.0		81.4880	83.7580	2.79	83.7652	83.6058	3.84 (1.151)	1.631
SP313/T300/S	787-13	394 K (250° F) "Wet"	78.5		79.5270	80.9890	1.84	80.9923	80.5228	3.76 (0.148)	1.570
NR150A2/T300/S (Hybrid)	NR-11	394 K (250° F) "Wet"	87.0		88.2320	89.1165	1.00	89.1010	88.8600	2.89 (0.153)	1.689
(Superhybrid) SP313/T300/S Ti+B/Al	PR-13	394 K (250° F) "Wet"	101.0		102.8770	103.4045	0.51	103.4322	103.3248	3.86 (0.152)	1.980
(Superhybrid) SP313/T300/S Ti+B/Al	SP-13	394 K (250° F) "Wet"	106.0		106.3210	106.6730	0.33	106.6776	106.6066	3.91 (0.154	1.945

Table LXXI. Task II Batch No. 2 Specimen Weight Records, 294 K (70° F) and 394 K (250° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights: Finished Weight	Specimen Conditioned Weights: Weight Prior to Drying (CTL)	Specimen Conditioned Weights: Fully Dried Weight (CTL)	Specimen Conditioned Weights: Wet Weight	Specimen Conditioned Weights: After Wet Spike Weight Percent	Specimen Conditioned Weights: Prior to Impact Weight (UDC)	Specimen Conditioned Weights: After Impact Weight (UDC)	Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
PR288/T300	785-11	294 K (70° F) "Wet Spike"	77.5		78.7450	81.2210	80.9980 (2.86%)	81.0163	80.8500	3.86 (0.152)	1.535
PR288/T300/S	786-11	294 K (70° F) "Wet Spike"	80.0		81.0230	83.2125	83.0340 (2.48%)	83.0485	80.7281	3.81 (0.150)	1.585
SP313/T300/S	787-11A	294 K (70° F) "Wet Spike"	81.0		81.6125	83.4385	83.2545 (2.01%)	83.2715	83.1439	3.86 (0.152)	1.558
NR150A2/T300/S (Hybrid)	NR-3*	294 K (70° F) "Wet Spike"	88.0		89.1065	90.0610	89.7720 (0.75%)	89.7869	89.6469	3.94 (0.155)	1.692
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-11	294 K (70° F) "Wet Spike"	101.0		103.1190	103.5960	103.4390 (0.31%)	103.4725	103.4782	3.91 (0.154)	1.971
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-11	294 K (250° F) "Wet Spike"	104.0		104.1870	104.4810	104.4510 (0.25%)	104.4661	104.4716	3.84 (0.151)	1.962
PR288/T300	785-14	394 K (250° F) "Wet Spike"	77		78.5245	81.0335	80.7980 (2.90%)	80.8032	80.5058	3.86 (0.152)	1.540
PR288/T300/S	786-14	394 K (250° F) "Wet Spike"	79.0		80.5790	82.9110	82.6990 (2.63%)	82.6957	79.7920	3.76 (0.148)	1.595
SP313/T300/S	787-14	394 K (250° F) "Wet Spike"	78.0		78.8250	80.3080	80.0800 (1.59%)	80.0918	78.7725	3.76 (0.148)	1.550
NR150A2/T300/S (Hybrid)	NR-5*	394 K (250° F) "Wet Spike"	89.0		89.6750	90.5640	90.3510 (0.75%)	90.3200	90.2755	3.86 (0.152)	1.695
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-14	394 K (250° F) "Wet Spike"	101.0		102.5085	103.0715	102.8745 (0.36%)	102.9225	102.1128	3.86 (0.152)	1.980
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-14	394 K (250° F) "Wet Spike"	101.0		101.8790	102.1346	102.1005 (0.22%)	102.1128	102.1043	3.78 (0.149)	1.990

*Batch No. 1 Specimen retested.

Table LXXII. Task II Batch No. 2 Specimen Weight Records, 394 K (250° F) "Dry".

Material	Specimen S/N	Impact Test Temp/Cond.	Specimen Conditioned Weights (grams)							Specimen Maximum Thickness mm (inches)	Specimen Density (grams/cc)
			Finished Weight	Weight Prior to Drying (CTL)	Fully Dried Weight (CTL)	Dry Weight	Weight Gain Percent	Prior to Impact Weight (UDC)	After Impact Weight (UDC)		
PR288/T300	785-12	394 K (250° F) "Dry"	77.5	78.9905	78.8160	79.5175	0.89	79.5224	79.2733	3.86 (0.152)	1.535
PR288/T300/S	786-12	394 K (250° F) "Dry"	80.0	81.1490	81.0032	81.5655	0.69	81.5837	81.2282	3.81 (0.150)	1.600
SP313/T300/S	787-12	394 K (250° F) "Dry"	78.0	79.3090	79.1065	79.5260	0.53	79.5332	78.9086	3.81 (0.150)	1.576
NR150A2/T300/S (Hybrid)	NR-10	394 K (250° F) "Dry"	88.0	89.5045	89.2750	89.7930	0.58	89.7808	89.7141	3.91 (0.154)	1.709
(Superhybrid; PR288/T300/S+ Ti+B/Al	PR- 12	394 K (250° F) "Dry"	102.0	103.474[illegible]	103.4550	103.5005	0.04	103.5234	103.4921	3.86 (0.152)	1.962
(Superhybrid; SP313/T300/S+ Ti+B/Al	SP-12	394 K (250° F) "Dry"	102.0	102.3585	102.3430	102.3670	0.02	102.3859	102.3767	3.76 (0.148)	2.000

Table LXXIII. Torsion Load Test Data, 219 K (-65° F) and 294 K (70° F) "Wet".

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-8	219 K (-65° F) "Dry"	400	377.7	274.6	-27.30
PR288/T300/S	786-8	219 K (-65° F) "Dry"	354	336.5	290.8	-13.60
SP313/T300/S	787-8	219 K (-65° F) "Dry"	349	332.7	302.2	- 9.17
NR150A2/T300/S (Hybrid)	NR-7	219 K (-65° F) "Dry"	417	363.0	381.0	+ 4.96
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-8	219 K (-65° F) "Dry"	655	680.4	489.8	+ 1.38
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-8	219 K (-65° F) "Dry"	624	657.1	680.0	+ 3.49
PR288/T300	785-9	294 K (70° F) "Dry"	400	380.3	330.9	-13.00
PR288/T300/S	786-9	294 K (70° F) "Dry	354	350.2	299.4	-14.50
SP313/T300/S	787-9	294 K (70° F) "Dry"	349	342.1	288.3	-15.70
NR150A2/T300/S (Hybrid)	NR-8	294 K (70° F) "Dry"	417	405.8	400.1	- 1.40
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-9	294 K (70° F) "Dry"	655	712.9	724.5	+ 1.63
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-9	294 K (70° F) "Dry"	624	719.3	760.9	+ 5.78

Table LXXIV. Torsion Load Test Data, 294 K (70° F) and 294 K (70° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-10	294 K (70° F) "Wet"	400	396.1	308.9	-22.0
PR288/T300/S	786-10	294 K (70° F) "Wet"	354	326.4	301.3	- 7.69
SP313/T300/S	787-10	294 K (70° F) "Wet"	349	338.1	249.5	-26.20
NR150A2/T300/S (Hybrid)	NR-9	294 K (70° F) "Wet"	417	381.9	370.0	- 3.12
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-10	294 K (70° F) "Wet"	655	647.7	671.6	+ 3.69
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-10	294 K (70° F) "Wet"	624	682.1	681.7	- 0.06
PR288/T300	785-11	294 K (70° F) "Wet Spike"	400	369.9	383.4	- 3.65
PR288/T300/S	786-11	294 K (70° F) "Wet Spike"	354	332.2	248.1	-25.30
SP313/T300/S	787-11A	294 K (70° F) "Wet Spike"	349	361.2	354.5	- 1.85
NR150A2/T300/S (Hybrid)	NR-3*	294 K (70° F) "Wet Spike"	417	391.3	380.0	- 2.89
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-11	294 K (70° F) "Wet Spike"	655	654.4	675.3	+ 3.19
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-11	294 K (25° F) "Wet Spike"	624	707.5	756.6	+ 6.94

*Batch No. 1 Specimen retested.

Table LXXV. Torsion Load Test Data, 394 K (250° F) "Dry" and 394 K (250° F) "Wet".

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-12	394 K (250° F) "Dry"	400	370.0	291.8	-21.10
PR288/T300/S	786-12	394 K (250° F) "Dry"	354	339.4	313.3	- 7.69
SP313/T300/S	787-12	394 K (250° F) "Dry"	349	347.8	309.4	-11.00
NR150A2/T300/S (Hybrid)	NR-10	394 K (250° F) "Dry"	417	414.8	386.5	- 6.82
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-12	394 K (250° F) "Dry"	655	681.8	676.7	- 0.75
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-12	394 K (250° F) "Dry"	624	659.5	651.5	- 1.21
PR288/T300	785-13	394 K (250° F) "Wet"	400	367.2	342.1	- 6.84
PR288/T300/S	786-13	394 K (250° F) "Wet"	354	354.5	351.1	- 0.96
SP313/T300/S	787-13	394 K (250° F) "Wet"	349	366.1	371.1	-25.90
NR150A2/T300/S (Hybrid)	NR-11	394 K (250° F) "Wet"	417	399.7	341.8	-14.50
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-13	394 K (250° F) "Wet"	655	650.0	673.2	+ 3.57
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-13	394 K (250° F) "Wet"	624	727.3	754.9	+ 3.79

Table LXXVI. Torsion Load Test Data, 394 K (250° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp.Cond.	Calib. Specimen Torsion Load 2° Twist	Conditioned Torsion Load 2° Twist	After Impact Torsion 2° Twist	Change in Torsion Load After Impact Percent
PR288/T300	785-14	394K (250° F) "Wet Spike"	400	356.4	155.5	-56.40
PR288/T300/S	786-14	394K (250° F) "Wet Spike"	354	336.3	243.7	-27.50
SP313/T300/S	787-14	394K (250° F) "Wet Spike"	349	349.9	218.6	-37.50
NR150A2/T300/S (Hybrid)	NR-5*	394K (250° F) "Wet Spike"	417	372.2	371.1	- 0.30
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-14	394K (250° F) "Wet Spike"	655	639.0	665.2	+ 4.10
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-14	394K (250° F) "Wet Spike"	624	669.3	700.7	+ 4.69

*Batch No. 1 Specimen retested.

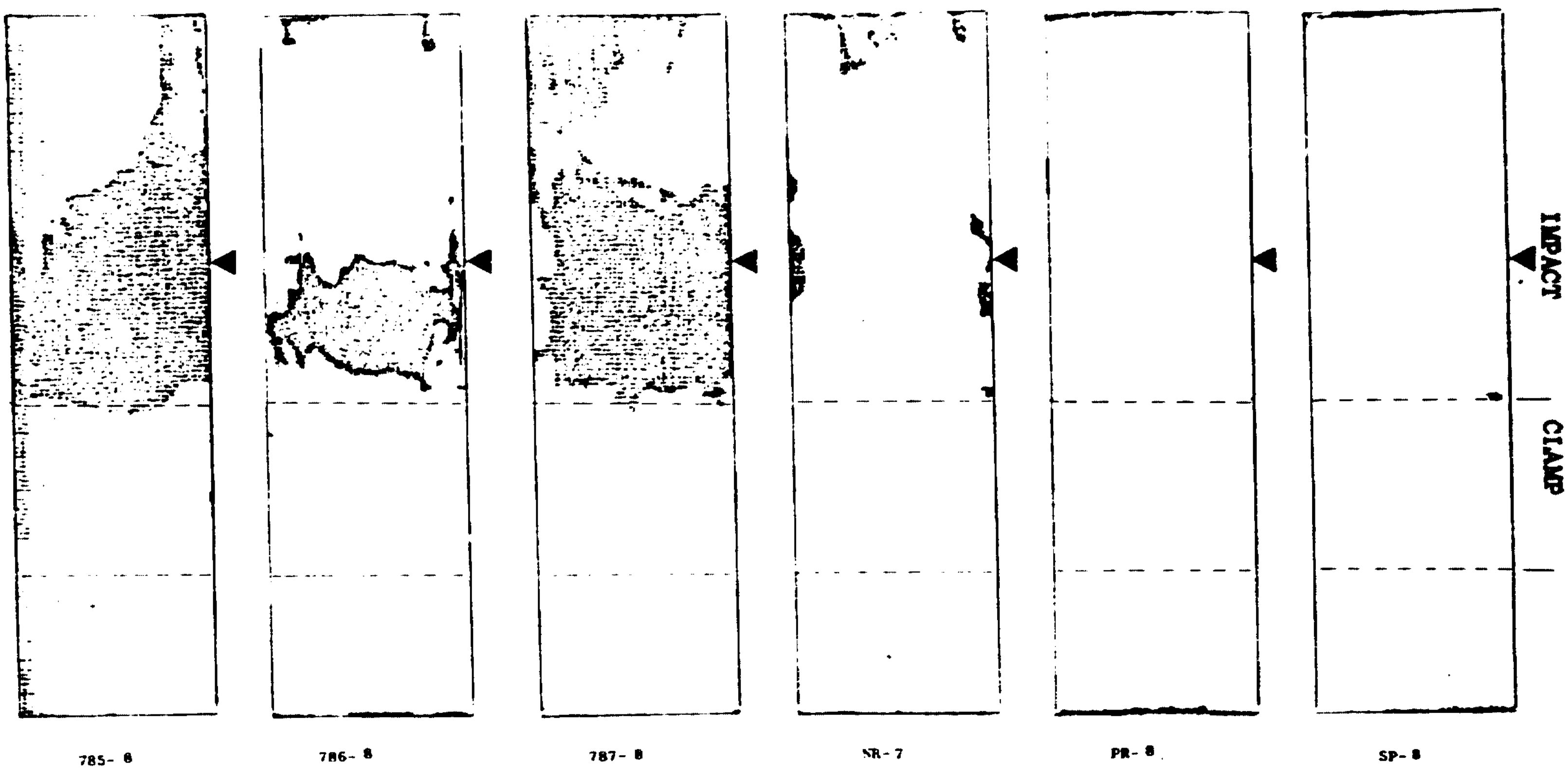


Figure 39. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 219 K (-65° F) "Dry" Specimens.

ORIGINAL PAGE IS OF POOR QUALITY

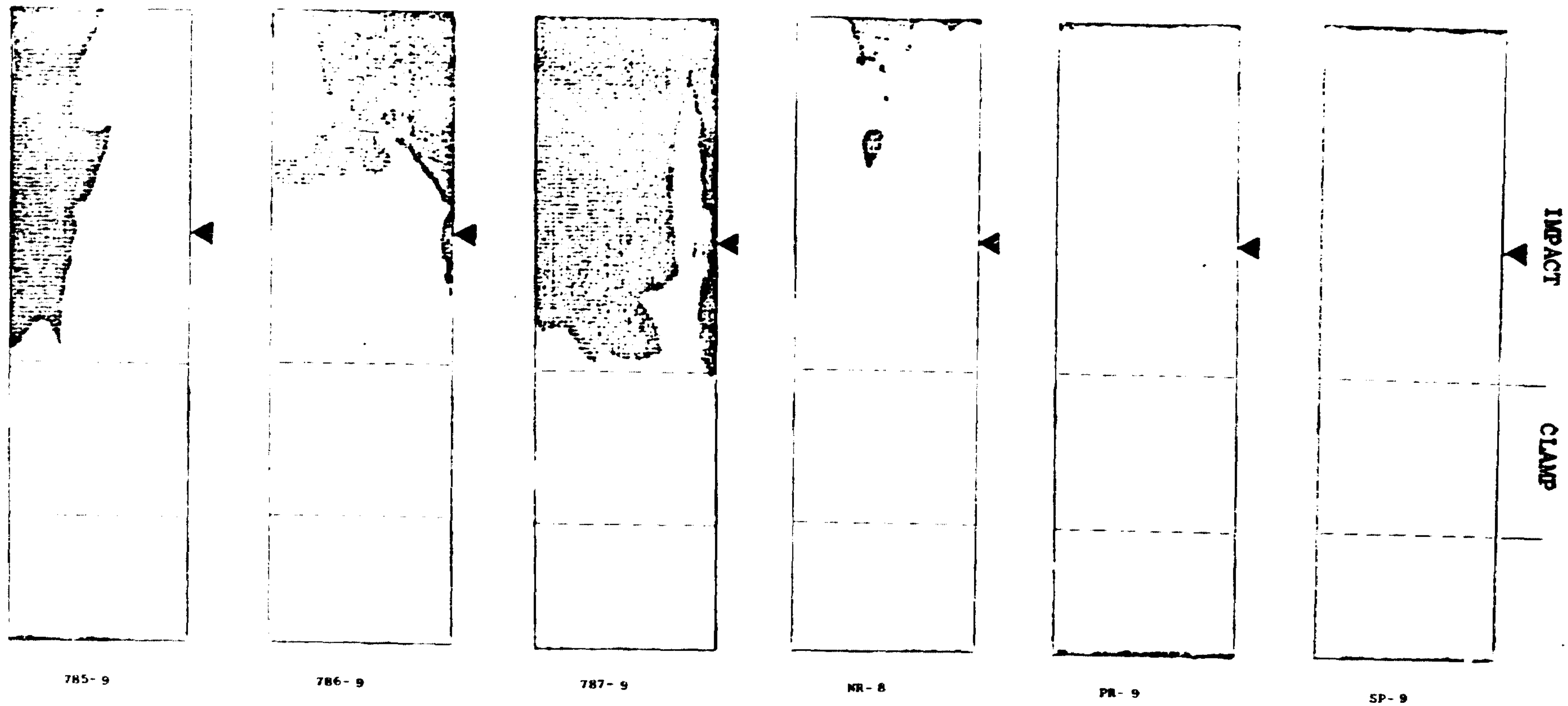


Figure 40. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Dry" Specimens.

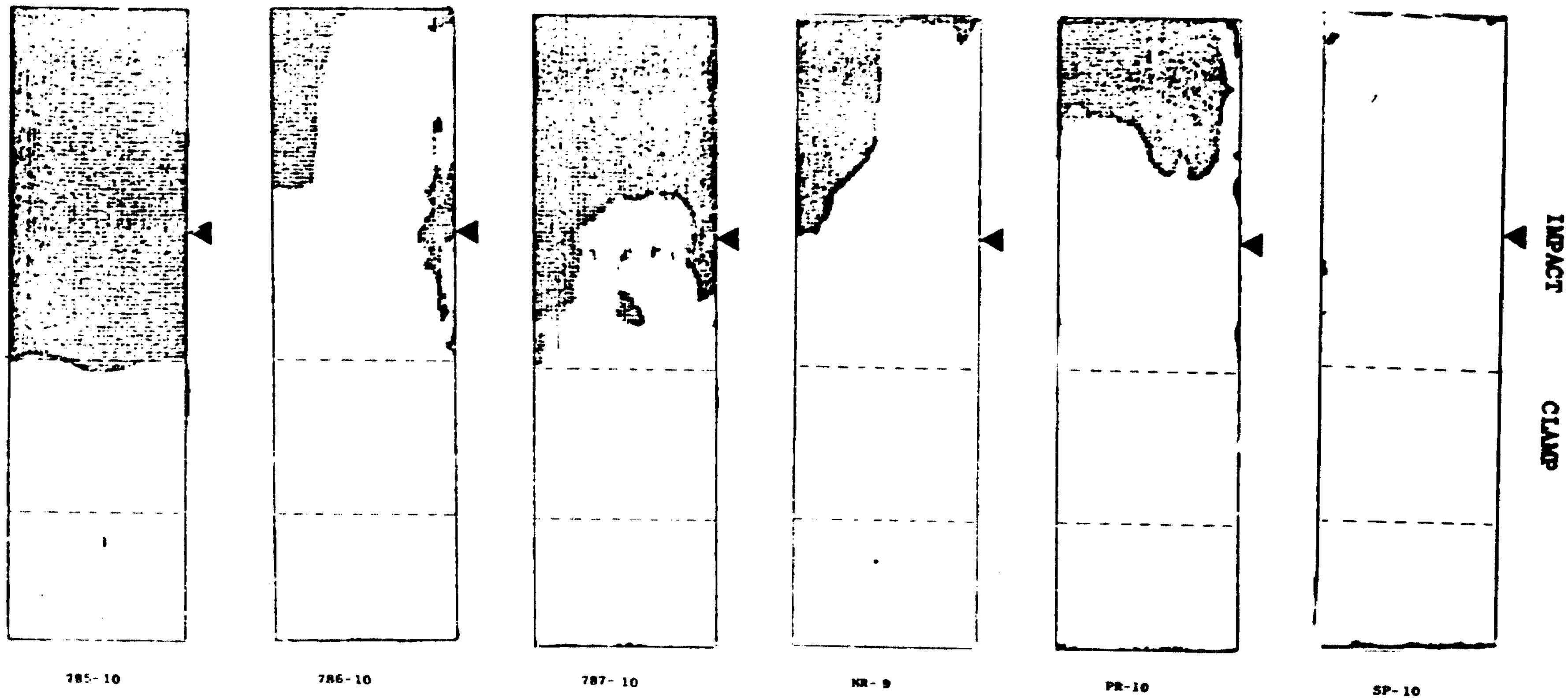


Figure 41. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Wet" Specimens.

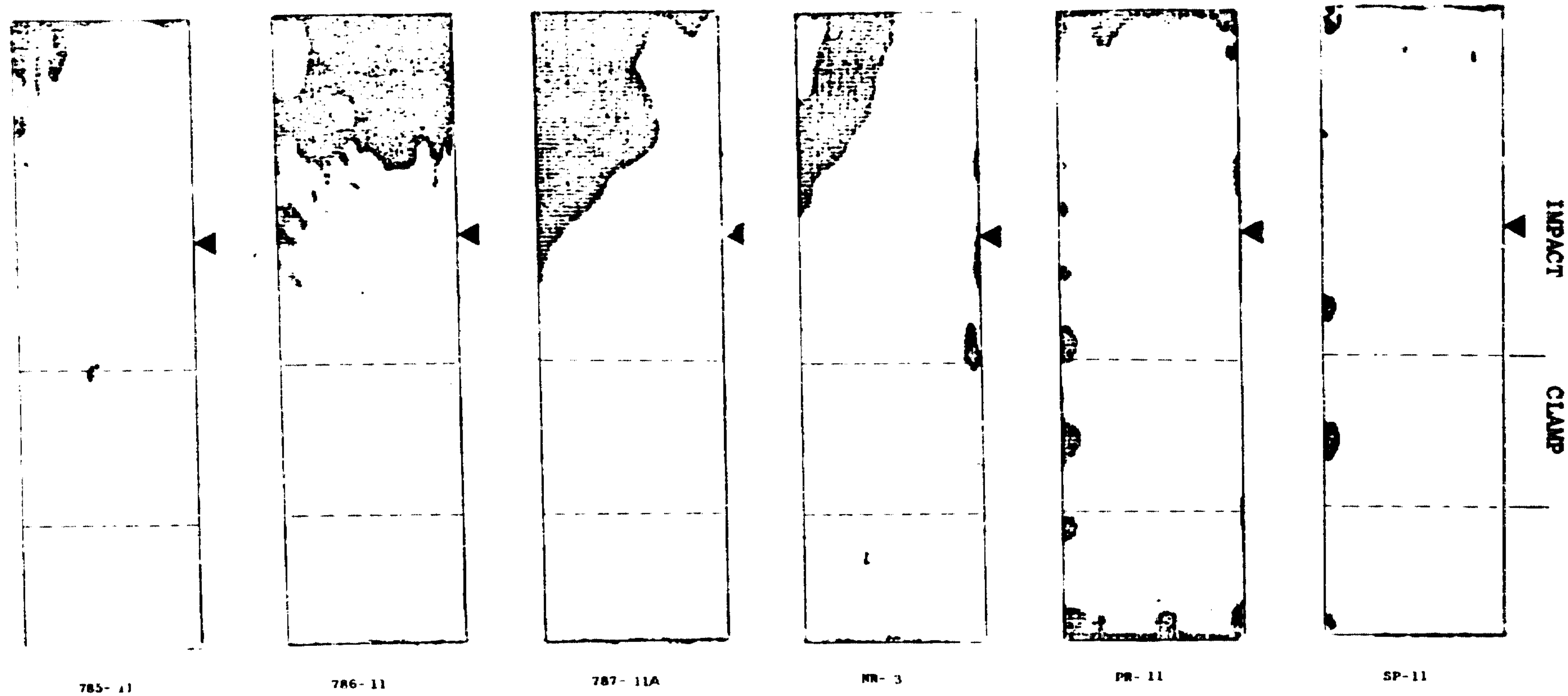


Figure 42. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 294 K (70° F) "Wet Spike" Specimens.

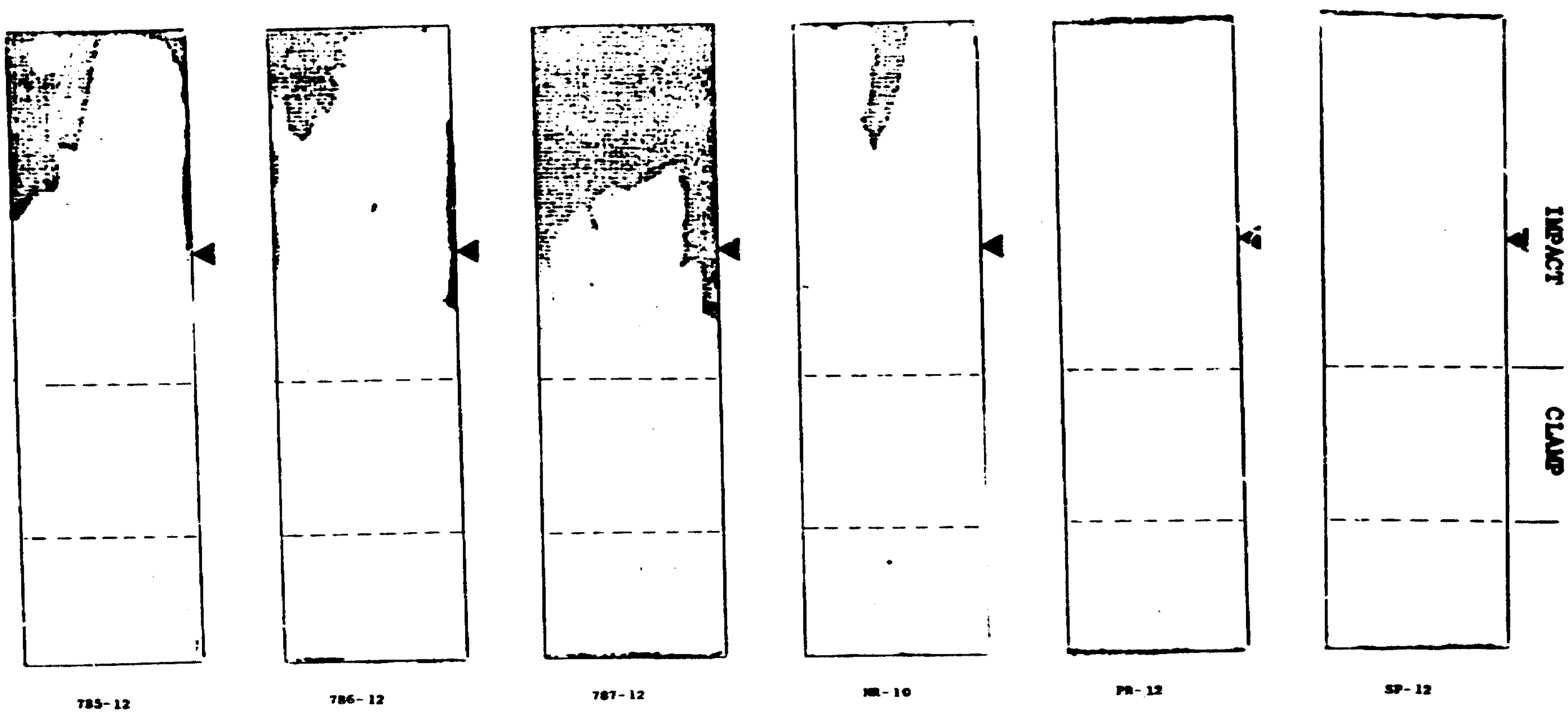


Figure 43. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 394 K (250° F) "Dry" Specimens.

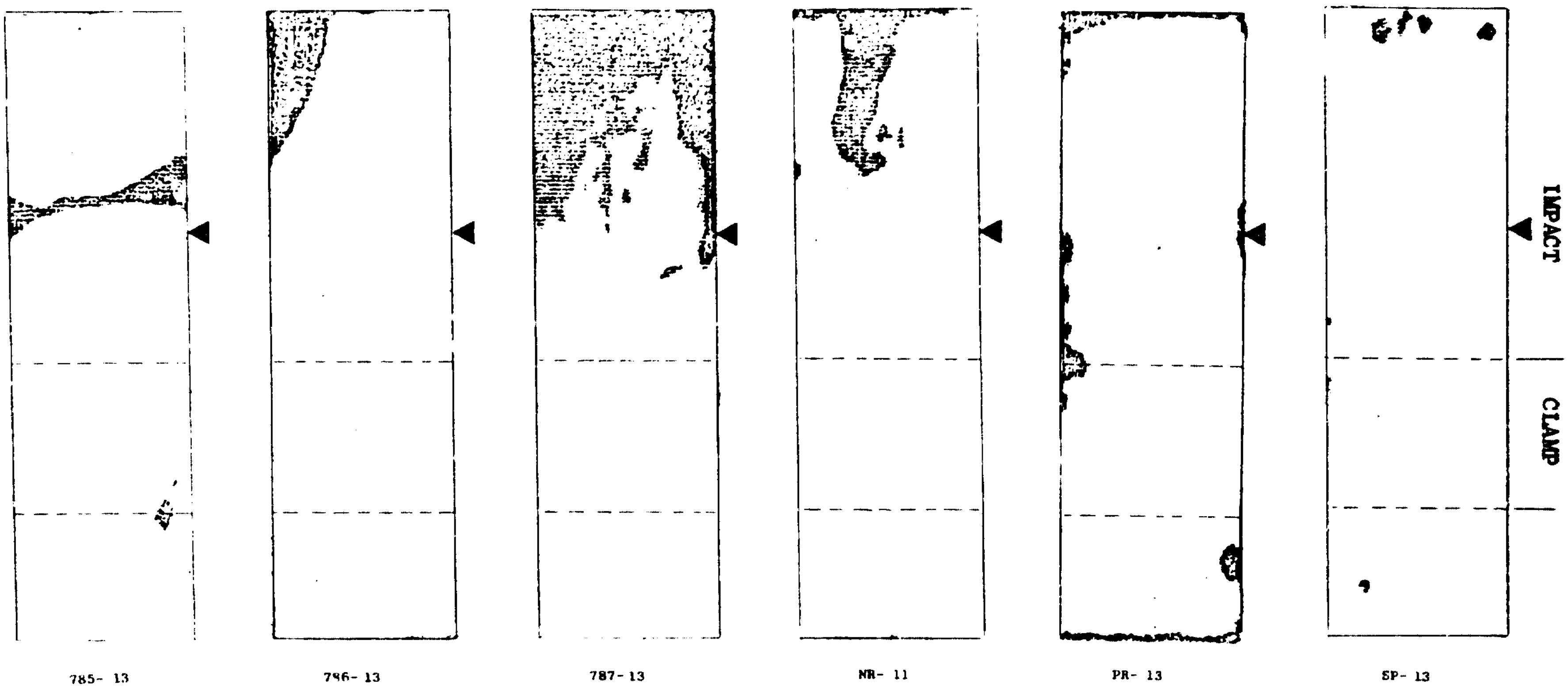


Figure 44. Task II - Batch No. 2 Specimens, NDE Ultrasonic C-Scan After Impact for 394 K (250° F) "Wet" Specimens.

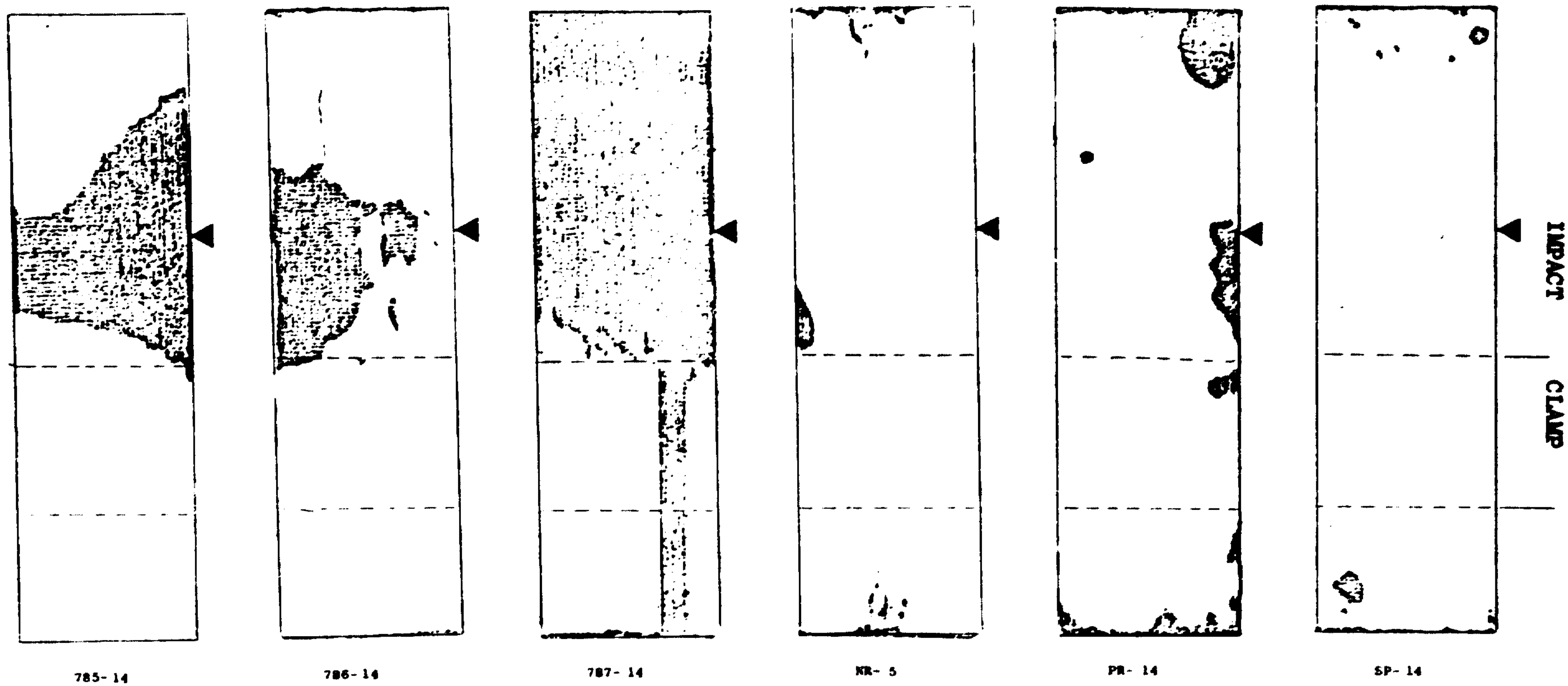


Figure 45. Task II - Batch No. 2 Specimens, Nde Ultrasonic C-Scan After Impact for 394 K (250° F) "Wet Spike" Specimens.

Table LXXVII. Task II Batch No. 2 NDE Specimen Evaluation and Impact Test Data, 219 K (-65° F) and 294 K (70° F) "Dry".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation					Impact Data		
			Initial C-Scan Results	Hand Scan Prior to Impact	Hand Scan After Impact $cm^2(in.^2)$	Final C-Scan $cm^2(in.^2)$	Visual Inspection Test	Velocity m/sec (ft/sec)	Slice Size (grams)	Normal Impact Energy Joules (ft-lb)
PR288/T30C	785-8	219 K (-65° F) "Dry"	No Indications	No Indications	94.52(14.65)	72.9(11.3)	Fractured at impact. Missing Mat'l at TE	277 (908)	7.52	51.5 (38.00)
PR288/T300/S	786-8	219 K (-65° F) "Dry"	No Indications	No Indications	78.7(12.20)	32.9(12.20)	Fractured at impact zone Cracked at TE	273 (895)	7.68	51.1 (37.70)
313/T300/S	787-8	219 K (-65° F) "Dry"	Slight Indications	No Indications	93.54(14.50)	69.7(10.8)	Completely fractured at TE and Impact zone	271 (889)	7.53	49.5 (36.50)
NR150A2/T300/S (Hybrid)	NR-7	219 K (-65° F) "Dry"	No Indications	No Indications	18.9(2.93)	12.9(2.0)	Missing outside plies 6.45 cm^2) (1 in^2) clamp cracks	274 (898)	7.62	51.0 (37.60)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-8	219 K (-65° F) "Dry"	Slight Indications	No Indications	-0-	Crack at Clamp 0.65(0.1)	Slight crack at clamp	280 (919)	7.67	53.7 (39.60)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-8	219 K (-65° F) "Dry"	No Indications	No Indications	-0-	6.45(1.0)	Cracked at Clamp	283 (929)	7.63	54.6 (40.30)
PR288/T300	785-9	294 K (70° F) "Dry"	No Indications	No Indications	53.81(8.34)	36.13(5.6)	Delam. Missing mat'l at TE	269 (881)	6.73	43.4 (32.00)
PR288/T300/S	786-9	K (79° F) Dry"	No Indications	No Indications	68.13(10.56)	41.9(6.5)	Delam. 113 cm^2 (17.5 $in.^2$)	270 (884)	7.53	48.8 (36.00)
SP313/T300/S	787-9	294 K (70° F) "Dry"	No Indications	No Indications	113.23(17.55)	91.6(14.2)	Delam. LE	274 (898)	7.50	51.3 (37.80)
NR150A2/T300/S (Hybrid)	NR-8	294 K (70° F) "Dry"	No Indications	No Indications	---	6.45(1.0)	6.45 cm2(1 in.2) Fracture	269 (882)	7.30	47.2 (34.80)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-9	294 K (70° F) "Dry"	Slight Indications	No Indications	1.29(0.2)	0.65(0.1)	No visual damage	271 (890)	7.01	46.1 (34.00)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-9	294 K (70° F) "Dry"	No Indications	No Indications	10.45(1.62)	No Indications	No visual damage	262 (858)	7.77	47.5 (35.00)

Table LXXVIII. Task II Batch No. 2 NDE Specimen Evaluation and Impact Test Data, 294 K (70° F) "Wet" and 294 K (70° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation: Initial C-Scan Results	Hand Scan Prior to Impact	Hand Scan After Impact	Final C-Scan	Visual Inspection Test	Impact Data: Velocity m/sec (ft/sec)	Slice Size (grams)	Normal Impact Energy Joules (ft-lb)
PR288/T300	785-10	294 K (70° F) "Wet"	No Indications	No Indications	113.2(17.55)	109.7(17.0)	Split 112.9 cm^2 (17.5 in.^{2}) Blisters	271 (890)	7.55	49.6 (36.60)
PR288/T300/S	786-10	294 K (70° F) "Wet"	No Indications	No Indications	51.4(7.96)	40.0(6.2)	Cracked/missing mat'l at impact zone and TE	280 (917)	7.50	52.3 (38.60)
SP313/T300/S	787-10	294 K (70° F) "Wet"	Slight Indications	No Indications	102.6(15.90)	77.4(12.0)	Delam/missing Mat'l at impact zone. Broomed TE	271 (890)	7.60	50.0 (36.90)
NR150A2/T300/S (Hybrid)	NR-9	294 K (70° F) "Wet"	No Indications	No Indications	26.3(4.08)	25.8(4.0)	Broken/split TE	265 (870)	7.66	48.1 (35.50)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-10	294 K (70° F) "Wet"	No Indications	5.50	38.1(5.90)	36.1(5.60)	Delam. 32.3 cm^2 (5 in.^{2})	260 (853)	7.63	46.1 (34.00)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-10	294 K (70° F) "Wet"	No Indications	No Indications	---	0.39(0.06)	Cracked at clamp	274 (899)	7.68	51.5 (38.00)
PR288/T300	785-11	294 K (70° F) "Wet Spike"	No Indications	No Indications	17.4(2.70)	12.9(2.0)	Delam/cracked TE Blisters	272 (893)	6.82	45.1 (33.30)
PR288/T300/S	786-11	294 K (70° F) "Wet Spike"	No Indications	No Indications	78.45(12.16)	48.4(7.5)	Missing mat'l at TE, cracks at Clamp	272 (893)	7.95	52.9 (39.00)
SP313/T300/S	787-11A	294 K (70° F) "Wet Spike"	No Indications	No Indications	44.2(6.85)	40.0(6.2)	Split/Broomed at TE	272 (892)	6.57	43.4 (32.00)
NR150A2/T300/S (Hybrid)	NR-3	294 K (70° F) "Wet Spike"	No Indications	No Indications	26.45(4.10)	25.8(4.0)	Split/Delam. TE Impact zone & Clamp	274 (898)	7.37	49.4 (36.40)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-11	294 K (70° F) "Wet Spike"	Slight Indications	1.10	7.09(1.10)	6.45(1.00)	No visual damage	253 (830)	7.86	44.9 (33.10)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-11	294 K (70° F) "Wet Spike"	No Indications	0.60	4.5(0.70)	3.2(0.50)	No visual damage	274 (897)	7.56	50.4 (37.20)

Table LXXIX. Task II Batch No. 2 NDE Specimen Evaluation and Impact Test Data, 394 K (250° F) "Dry" and 394 K (250°F) "Wet".

Material	Specimen S/N	Impact Test Temp/Cond.	Nondestructive Evaluation: Initial C-Scan Results	Nondestructive Evaluation: Hand Scan Prior to Impact	Nondestructive Evaluation: Hand Scan After Impact cm^2(in.^{2})	Nondestructive Evaluation: Final C-Scan cm^2(in.^{2})	Nondestructive Evaluation: Visual Inspection Test	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size (grams)	Impact Data: Normal Impact Energy Joules (ft-lb)
PR288/T300	785-12	394 K (250° F) "Dry"	No Indications	No Indications	71.4(11.06)	30.3(4.7)	Split/missing mat'l at impact	276 (906)	7.30	49.8 (36.70)
PR288/T300/S	786-12	394 K (250° F) "Dry"	No Indications	No Indications	53.4(8.28)	16.8(2.6)	Split/missing mat'l at impact zone and TE	271 (890)	7.71	40.7 (37.40)
SP313/T300/S	787-12	394 K (250° F) "Dry"	No Indications	No Indications	63.9(9.90)	64.5(10.0)	Badly split/dela[illegible] TE and impact zone.	283 (927)	7.56	54.2 (40.00)
NR150A2/T300/S (Hybrid)	NR-10	394 K (250° F) "Dry"	No Indications	No Indications	10.6(1.64)	7.7(1.2)	Cracks middle (only one side)	278 (911)	7.42	51.1 (37.70)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-12	394 K (250° F) "Dry"	No Indications	No Indications	3.7(0.58)	No Indications	Dent/peel at Impact zone 3.2 cm2 (0.5 in.2)	277 (909)	7.67	52.6 (38.80)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-12	394 K (250° F) "Dry"	No Indications	No Indications	---	No Indications	No visual damage	273 (895)	7.46	49.6 (38.60)
PR288/T300	785-13	394 K (250° F) "Wet"	No Indications	No Indications	19.5(3.03)	12.9(2.0)	Broken in half at Impact	254 (833)	6.79	39.3 (29.00)
PR288/T300/S	786-13	394 K (250° F) "Wet"	No Indications	No Indications	18.3(2.84)	10.9(1.7)	Split open TE	251 (823)	7.06	39.7 (29.30)
SP313/T300/S	787-12	394 K (250° F) "Wet"	Slight Indications	No Indications	83.9(13.00)	54.8(8.5)	Broken/delam TE & eracted impact zone	265 (869)	7.72	51.1 (37.70)
NR150A2/T300/S (Hybrid)	NR-11	394 K (250° F) "Wet"	Slight Indications	No Indications	16.1(2.5)	14.8(2.3)	Broken TE Cracks at clamp	259 (850)	7.57	45.4 (33.50)
(Superhybrid) PR288/T300/S+ Ti+B/Al	PR-13	394 K (25[illegible]) "Wet"	No Indications	0.23	9.7(1.50)	[illegible].45(1.0)	Dent/peel at impact zone. Delam TE	266 (873)	7.16	45.2 (33.40)
(Superhybrid) SP313/T300/S+ Ti+B/Al	SP-13	394 K (250° F) "Wet"	No Indications	0.70	5.8(0.90)	3.9(0.60)	No visual [illegible]	263 (861)	7.11	43.8 (32.3)

Table LXXX. Task II Batch No. 2 NDE Specimen Evaluations Impact Test Data, 394 K (250° F) "Wet Spike".

Material	Specimen S/N	Impact Test Temp./Cond.	Nondestructive Evaluation: Initial C-Scan Results	Nondestructive Evaluation: Hand Scan Prior to Impact	Nondestructive Evaluation: Hand Scan After Impact cm^2 (in^2)	Nondestructive Evaluation: Final C-Scan cm^2 (in^2)	Visual Inspection Test	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size (grams)	Impact Data: Normal Impact Energy Joules (ft-lb)
PR288/T300	785-14	394 K (250° F) "Wet Spike"	No Indications	0.60	68.4(10.60)	51.6(8.0)	Completely broken thru at impact zone	278 (910)	7.20	49.5 (36.50)
PR288/T300/S	786-14	394 K (250° F) "Wet Spike"	No Indications	No Indications	94.2(14.60)	52.3(8.1)	Broken/missing Material LE Clamp Cracks	277 (907)	7.83	53.4 (39.40)
SP313/T300/S	787-14	394 K (250° F) "Wet Spike"	Porosity Indications	No Indications	117.0(18.15)	106.5(16.5)	Completely split open 113 cm^2 (17.5 $in.^2$)	285 (933)	7.60	54.9 (40.50)
NR150A2/T300/S (Hybrid)	NR-5	394 K (250° F) "Wet Spike"	Slight Indications	No Indications	10.7(1.66)	9.7(1.5)	Small cracks and surface delam.	263 (861)	6.92	42.6 (31.40)
PR288/T300/S+ Ti+B/Al (Superhybrid)	PR-14	394 K (250° F) "Wet Spike"	No Indications	0.75	5.0(0.77)	19.4(3.0)	Deformed at Impact zone	273 (894)	7.07	46.9 (34.60)
SP313/T300/S+ Ti+B/Al (Superhybrid)	SP-14	394 K (250° F) "Wet Spike"	No Indications	0.90	7.4(1.15)	3.2(0.5)	Slight peeling at impact zone Delam. TE	279 (914)	7.63	52.9 (39.00)

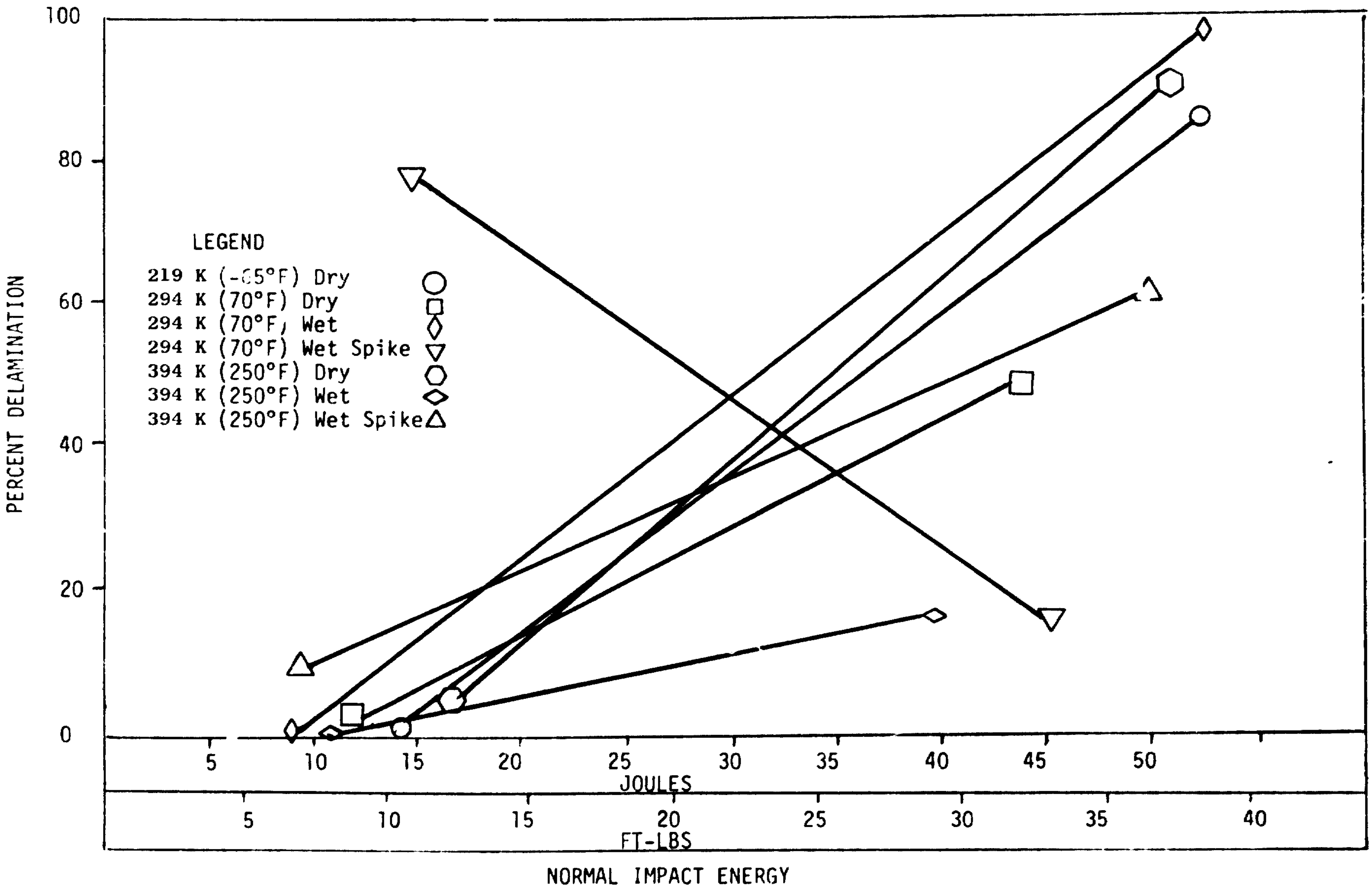


Figure 46. Impact Energy/Delamination Correlation for PR288/T300.

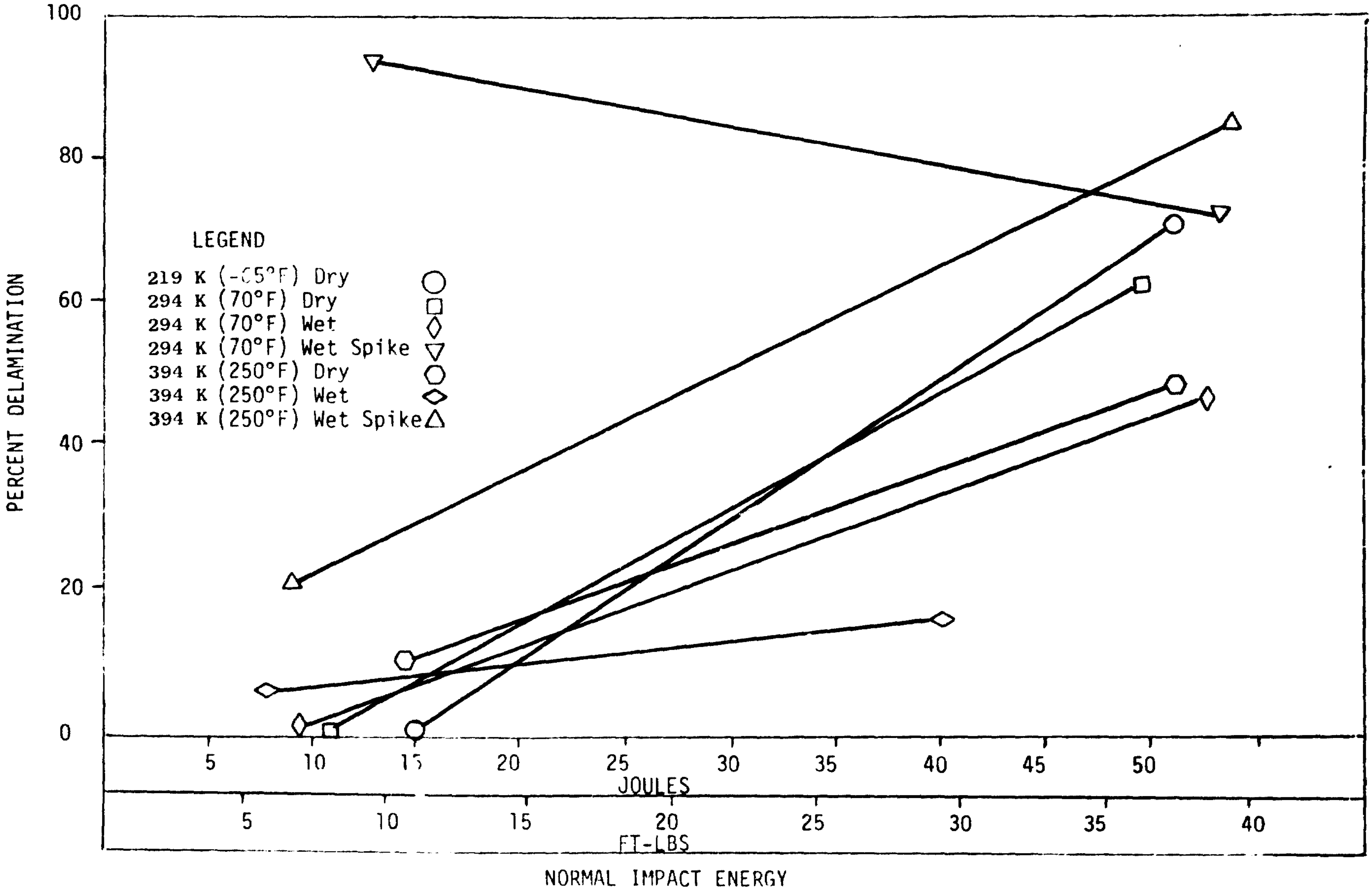


Figure 47. Impact Energy/Delamination Correlation for PR288/T300/S (Hybrid).

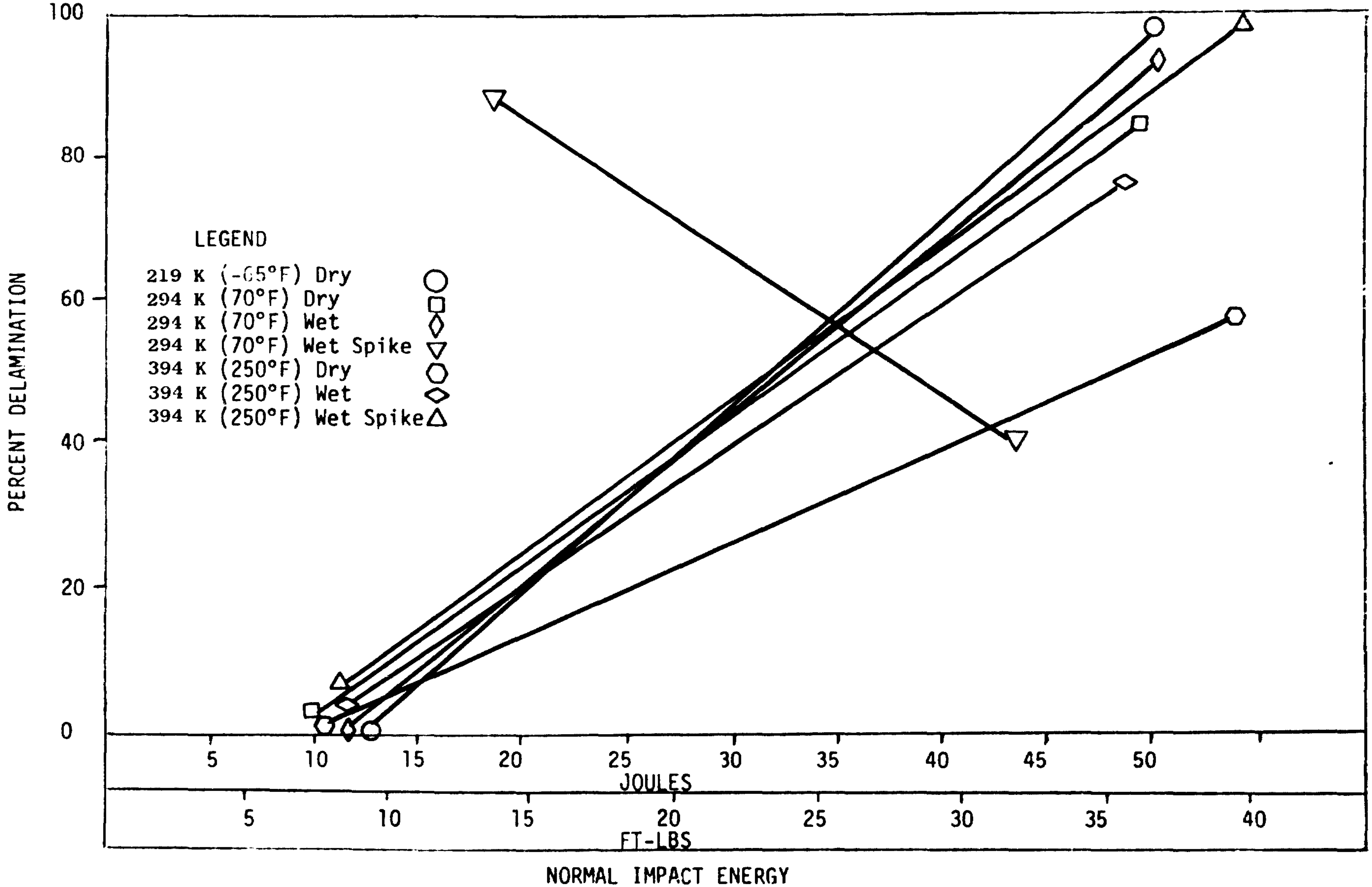


Figure 48. Impact Energy/Delamination Correlation for SP313/T300/S (Hybrid).

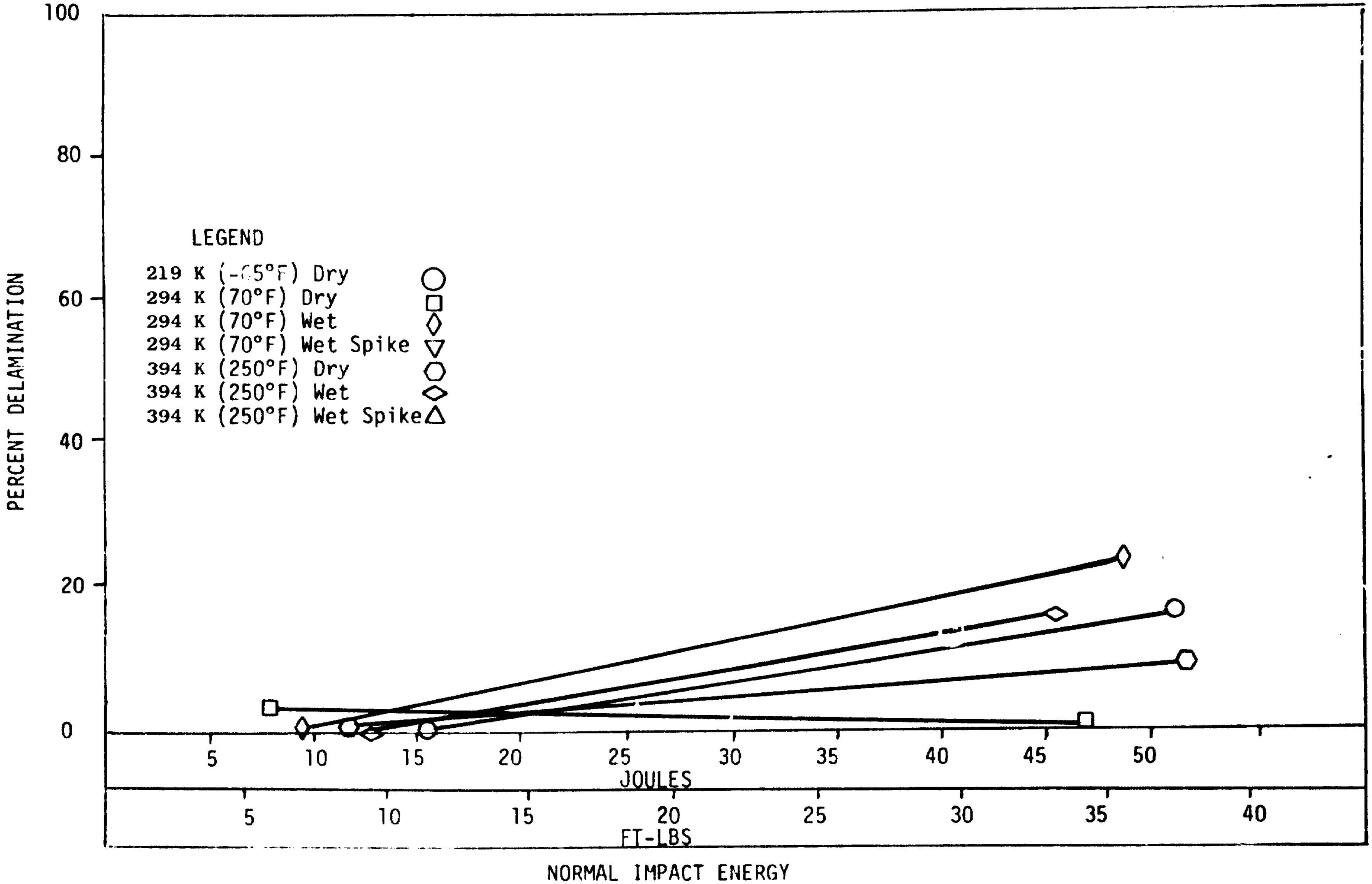


Figure 49. Impact Energy/Delamination Correlation for NR150A2/T300/S (Hybrid).

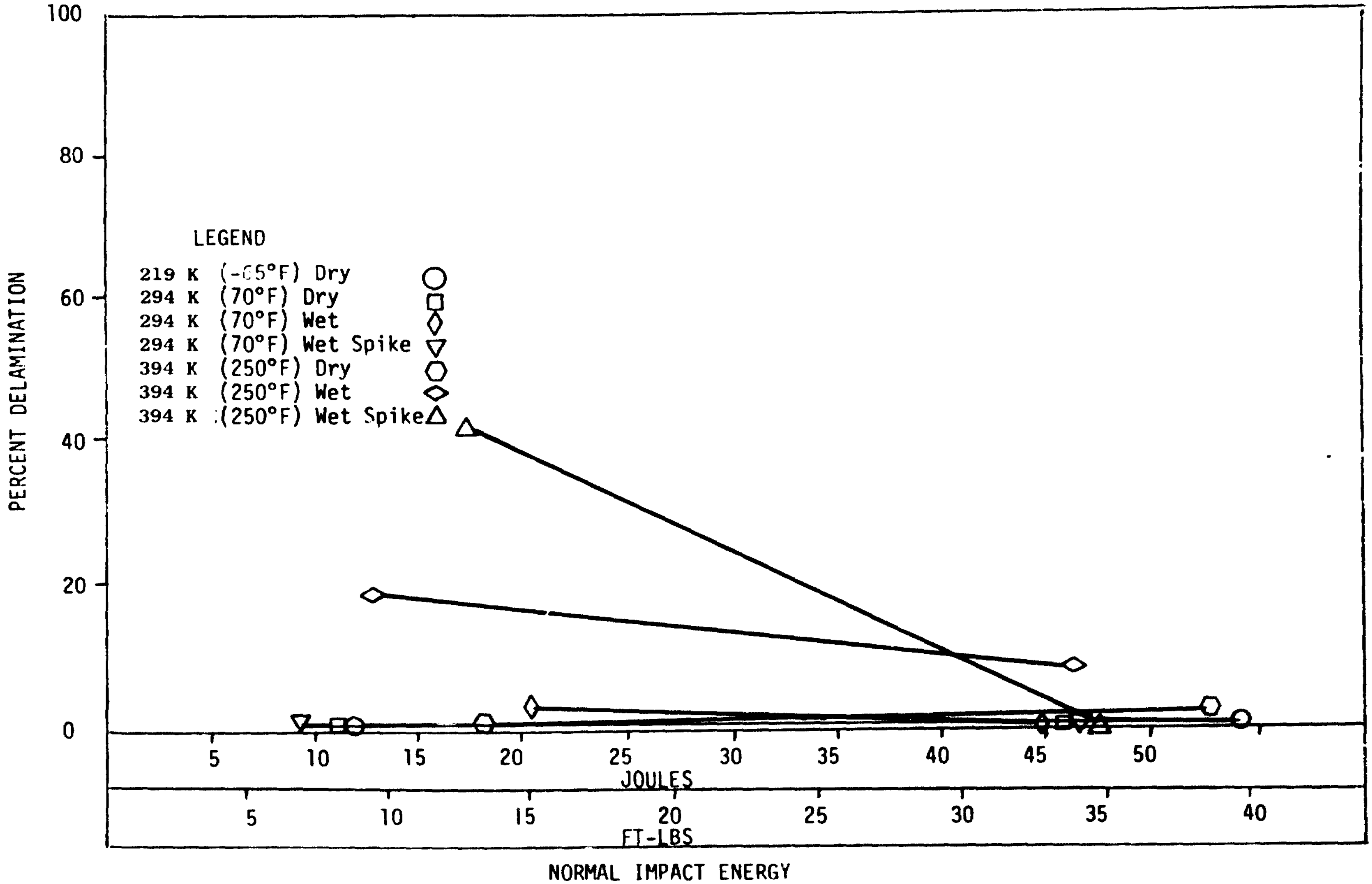


Figure 50. Impact Energy/Delamination Correlation for PR288/T300/S + Ti + B/Al (Superhybrid).

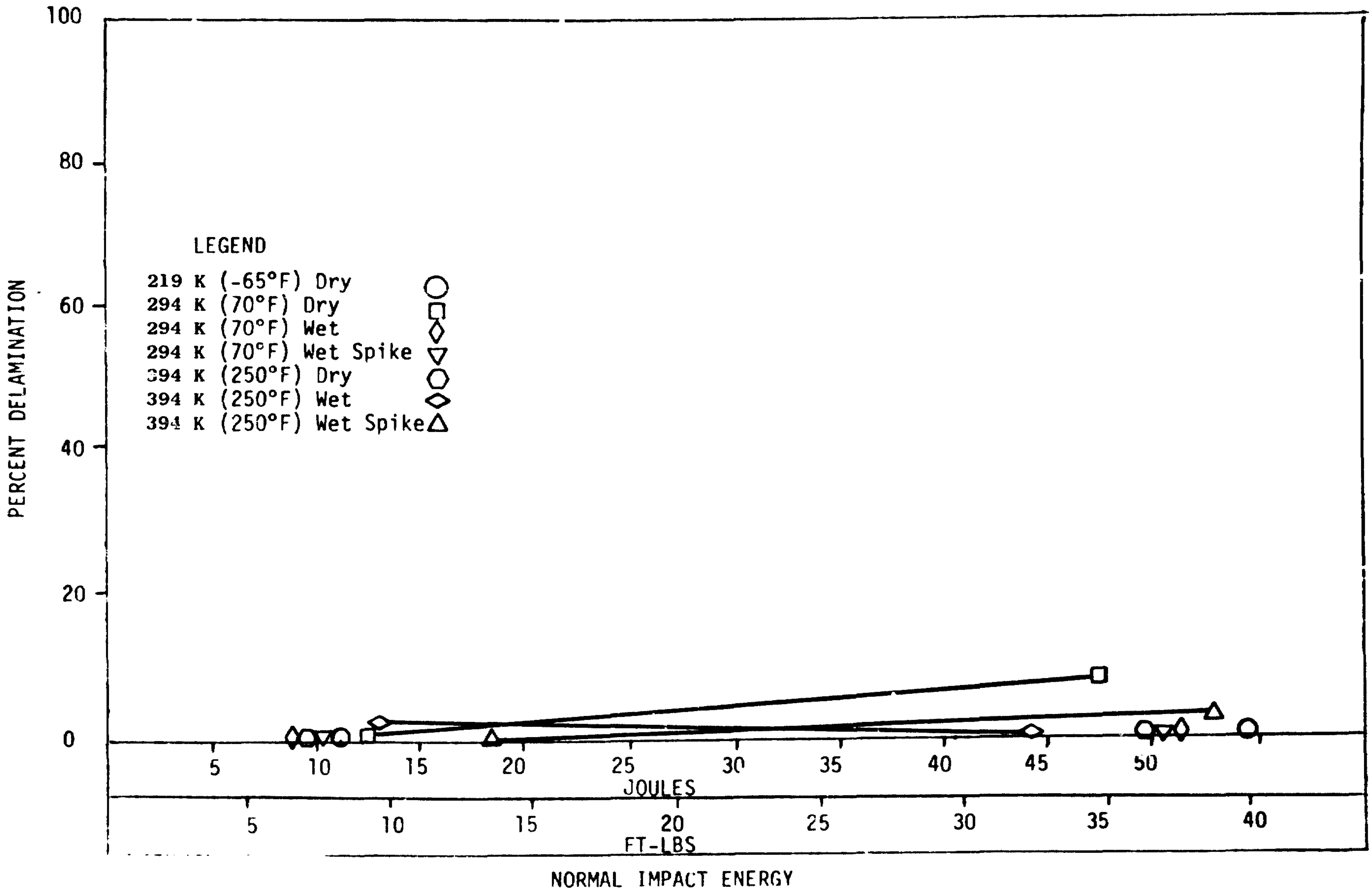


Figure 51. Impact Energy/Delamination Correlation for SP313/T300/S + Ti + B/Al (Superhybrid).

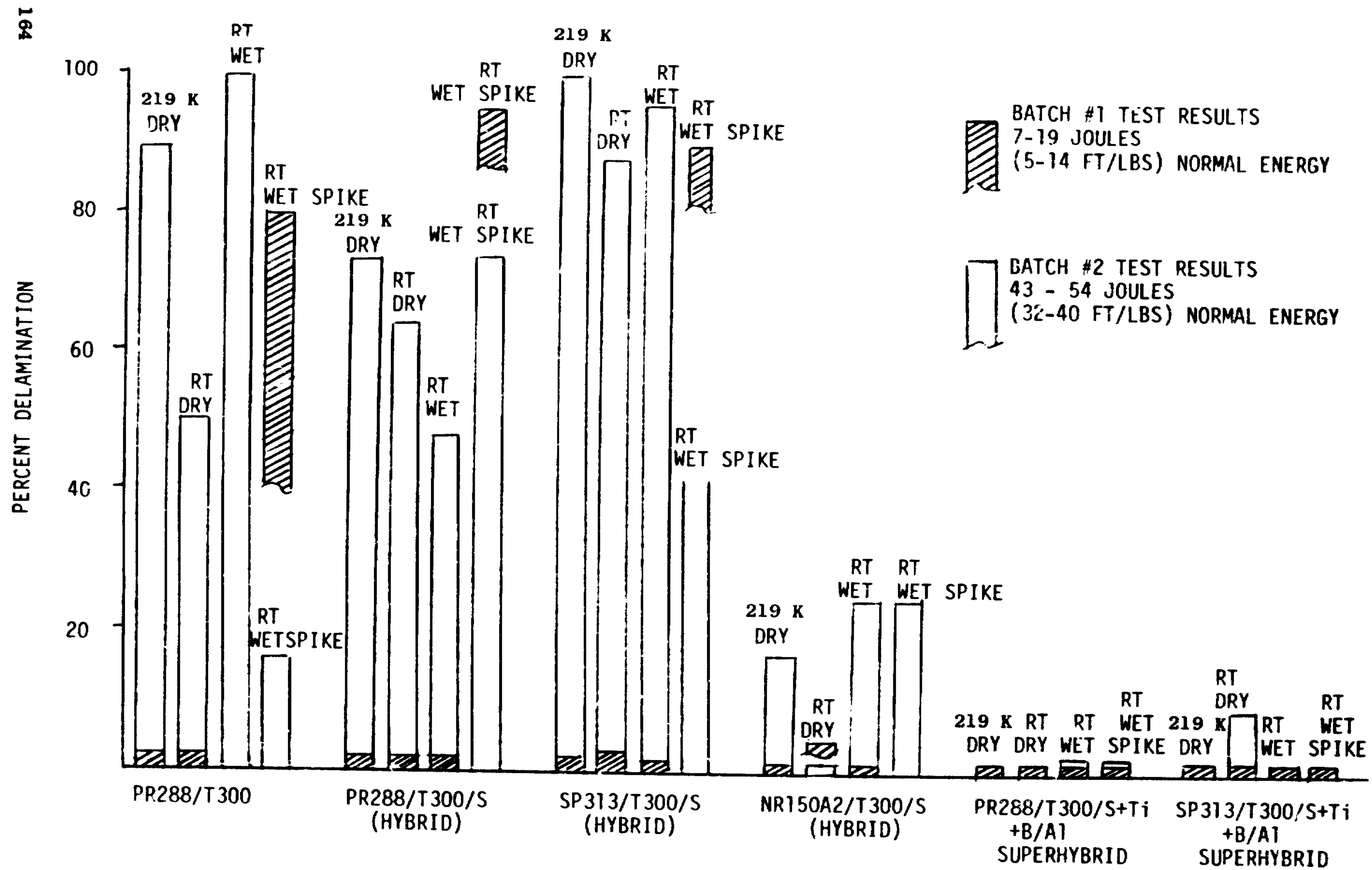


Figure 52. Damage Comparison for 219 K (-65° F) and Room Temperature Environmental Specimens.

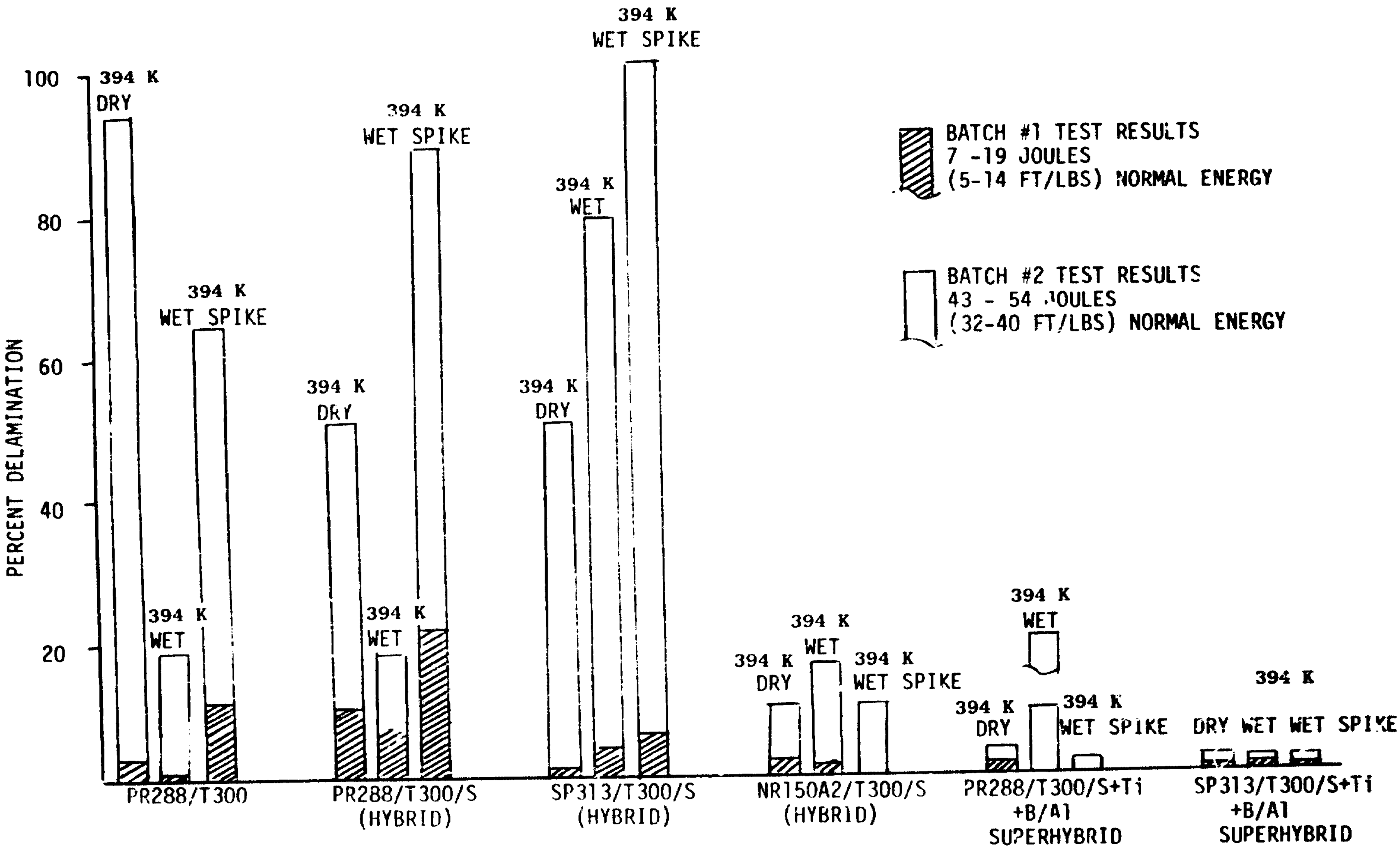


Figure 53. Damage Comparison for 394 K (250° F) Environmental Specimens.

Table LXXXI. Batch No. 2 Environmental Specimens Ranking By Test.

Test Condition	Specimen Dash No.	Ranking					
		1	2	3	4	5	6
219 K (-65° F) "Dry"	-1	SP	PR	NR	786	785	787
294 K (70° F) "Dry"	-2	PR	NR	SP	785	786	787
294 K (70° F) "Wet"	-3	SP	PR	NR	786	787	785
294 K (70° F) "Wet Spike"	-4	SP	PR	785	NR	787	786
394 K (250° F) "Dry"	-5	SP	PR	NR	786	787	785
394 K (250° F) "Wet"	-6	SP	PR	NR	786	785	787
394 K (250° F)	-7	PR	SP	NR	785	786	787

Legend:

785 PR288/T300 (Baseline)
786 PR288/T300/S Hybrid
787 SP313/T300/S Hybrid
NR NR150A2/T300/S Hybrid
PR PR288/T300/S+Ti+B/Al Superhybrid
SP SP313/T300/S+Ti+B/Al Superhybrid

Table LXXXII. Batch No. 2 Environmental Specimen Rating by Design.

Test Condition	Specimen Design Points - Equal Rating					
	785	786	787	NR	PR	SP
219 K (-65° F) "Dry"	5	4	6	3	2	1
294 K (70° F) "Dry"	4	5	6	2	1	3
294 K (70° F) "Wet"	6	4	5	3	2	1
294 K (70° F) "Wet Spike"	3	6	5	4	2	1
394 K (250° F) "Dry"	4	4	5	3	2	1
394 K (250° F) "Wet"	5	4	6	3	2	1
394 K (250° F) "Wet Spike"	4	5	6	3	1	2
Total Points Actual	31	32	39	21	12	10
Ranking Order	4	5	6	3	2	1

Legend:

785 PR288/T300 Baseline
786 PR288/T300/S Hybrid
787 SP313/T300/S Hybrid
NR NR150A2/T300/S Hybrid
PR PR288/T300/S+Ti+B/Al Superhybrid
SP SP313/T300/S+Ti+B/Al Superhybrid

- The PR288 graphite and hybrid composite specimens exhibited similar impact damage characteristics with considerable delamination in nearly all the environmental conditions of 274 m/sec (900 ft/sec). No definitive trends could be observed in the data for these two materials (See Figures 46 and 47) with the exception of the 294 K (250° F) "Wet" conditions which appeared to have the least damage at the higher energy level. This could be the result of a slightly lower energy level of 39.3 joules (29 ft-lb) for these two tests compared to the 47.5 to 54.3 joules (35 to 40 ft-lb) range for the majority of the other conditions.

- The SP313 hybrid composite specimens exhibited similar impacted characteristics as the PR288 composite specimens with the majority of the Batch No. 2 higher energy impact damage falling in the 60 to 100 percent range. This is illustrated in Figure 48.

- The NR150A2 hybrid composite specimen exhibited considerably better resistance to impact damage than either the PR288 or the SP313 composites with the damage levels on all specimens being less than 25 percent. The 294 K (70° F) and 394 K (250° F) "Dry" conditioned specimens exhibited the least damage and the 294 K (70° F) "Wet" and "Wet Spike" conditioned specimens the most damage.

- Both the PR288 and the SP313 superhybrid specimens exhibited superior resistance to impact damage at all levels of conditioning compared to solid polymeric composite laminates. In the case of the two superhybrids, the SP313/T300/S + Ti+B/Al appears to offer a slight advantage with the majority of data falling below the 2 percent damage level (see Figures 50 and 51), being insensitive to environmental conditioning.

5.0 TASK III - LEADING EDGE IMPACT PROTECTION SYSTEMS

Based upon the ballistic impact test results of Task II, one hybrid and one superhybrid system was selected and used for the fabrication of larger simulated blade test panels. The specimens were reinforced with a leading edge protection device prior to conducting ballistic impact tests. Initially NR150A2/T300/S superhybrid and SP313/T300/S superhybrid were the selected systems, but due to processing problems associated with the NR150A2 system, the NASA developed PMR15 polyimide was finally substituted.

5.1 SPECIMEN DESIGN

The Task III specimen was a larger simulated airfoil design than that used in Task II, measuring 15.24 cm (6 in.) chord and 40.64 cm (16 in.) long with a maximum thickness of 6.35 mm (0.25 in.). The final protection device selected consisted of nickel plated wire mesh applied to the leading edge over a 7.62 cm (3 in.) chordal length. Figure 54 shows the basic cross-section geometry of the specimen which was also selected for Task IV - Simulated Blade Spin Impact Tests.

The ply orientation/layup selected for the two designs of specimen are diagramatically shown in Figures 55 Hybrid Design and 56 Superhybrid Design. A photograph of the typical specimens are shown in Figure 57 and the cross section construction is shown in Figure 58.

The materials initially procured for Task III were subjected to incoming materials quality control procedures. Physical properties of the prepregs and mechanical properties of the molded test panels are tabulated in the attached Q.C. Data Summary Sheets, Table LXXXIII - SP313/T300/S and Table LXXXIV - NR150A2/T300/S. The materials were released for specimen fabrication based upon the acceptable mechanical properties in molded laminates.

5.2 SPECIMEN FABRICATION

5.2.1 Hybrid Specimens - (NR150A2/T300/S)

The initial NR150A2 Process Evaluation flat panels molded in accordance with the procedures developed for the Task II specimens (Ref: Paragraph 4.3) were of unacceptable quality/finish despite acceptable Q.C. mechanical properties. Once again batch to batch material variability was suspected. This necessitated a complete re-evaluation of the molding/processing parameters for the new batch of prepreg. Some ten additional flat panels were produced varying initial staging temperature/times, "PreDoT" die temperatures/pressures and residual solvent content in attempts to secure a satisfactory process.

An interesting discovery made during the process evaluation study was that absorbed moisture in the fully cured laminate creates increased resin matrix flow during the "PreDoT" post die forming procedure. A press cured

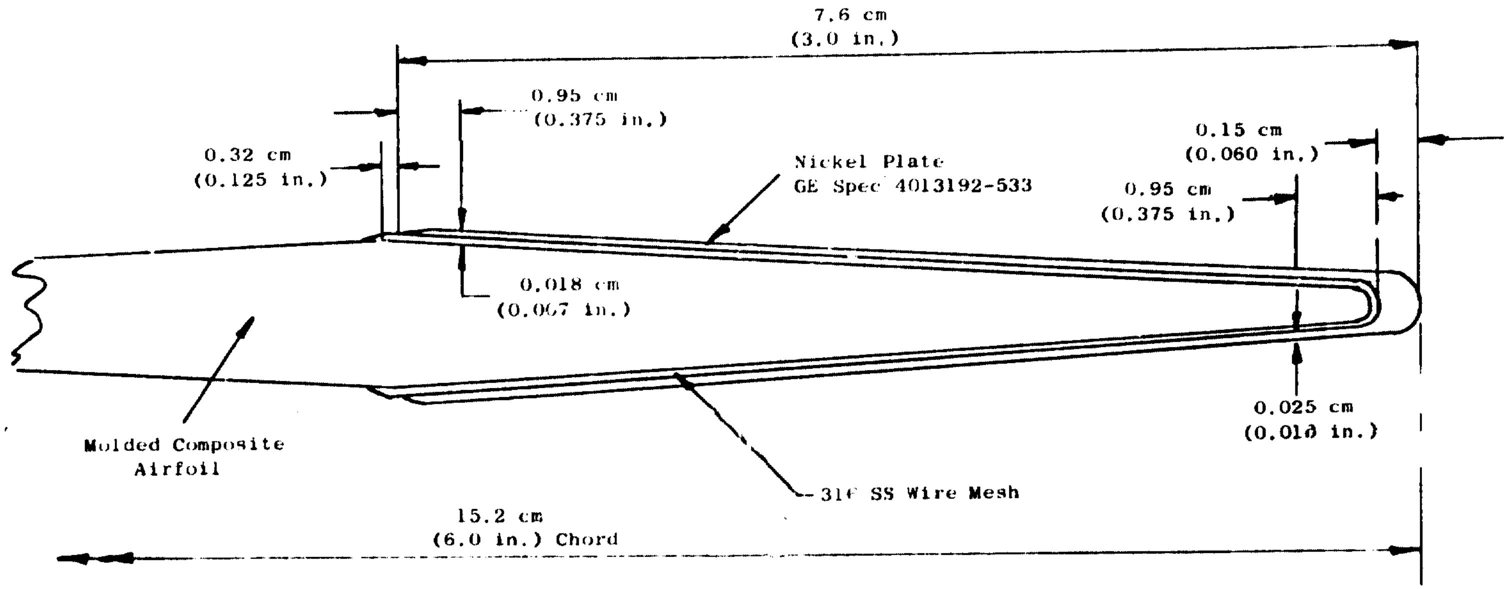
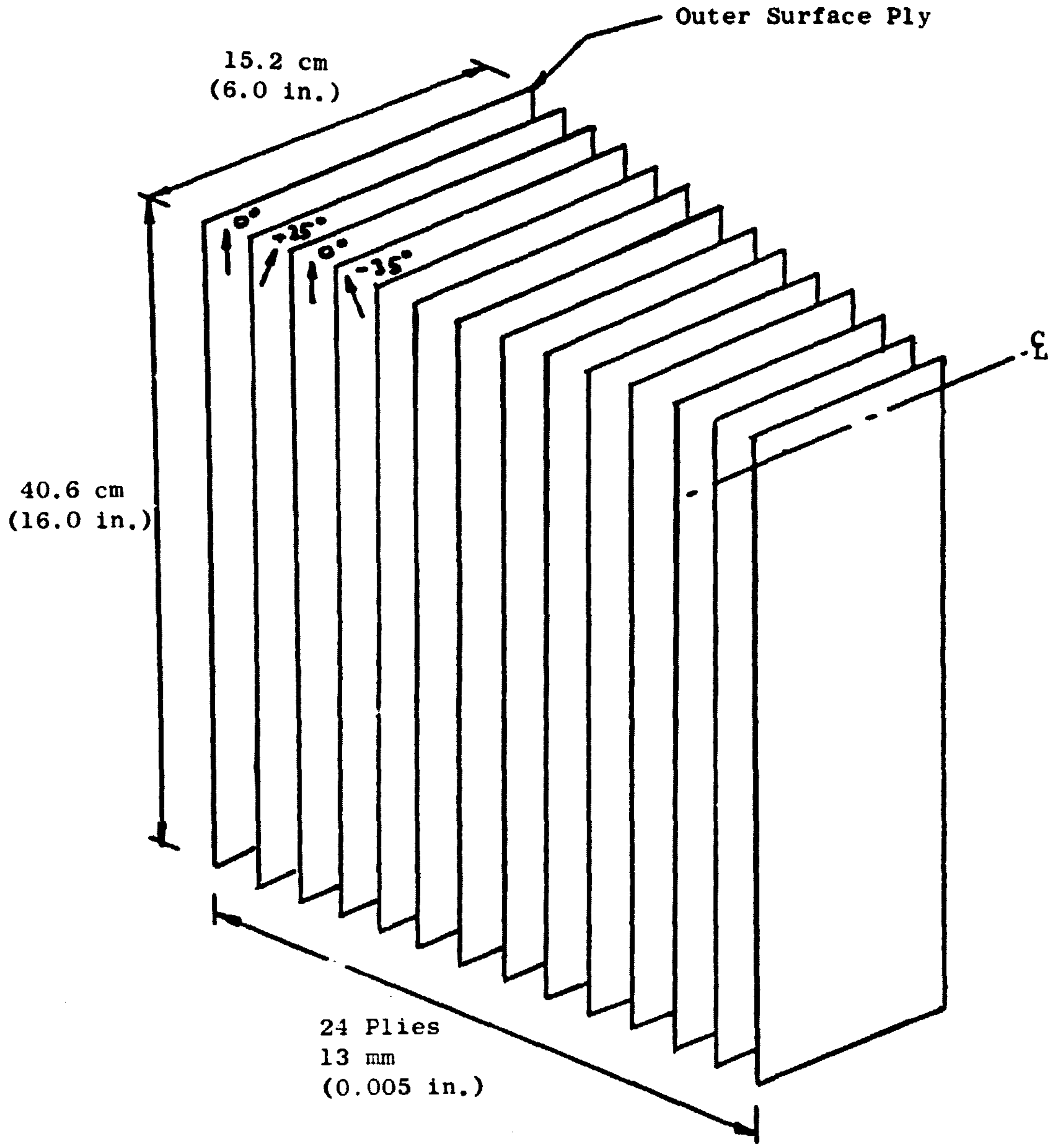


Figure 54. Tasks III and IV Simulated Airfoil Specimen Design (Specimen Length 40.6 cm (16.0 in.).



Hybrid Design

Figure 55. Hybrid Design Specimen Ply Orientation.

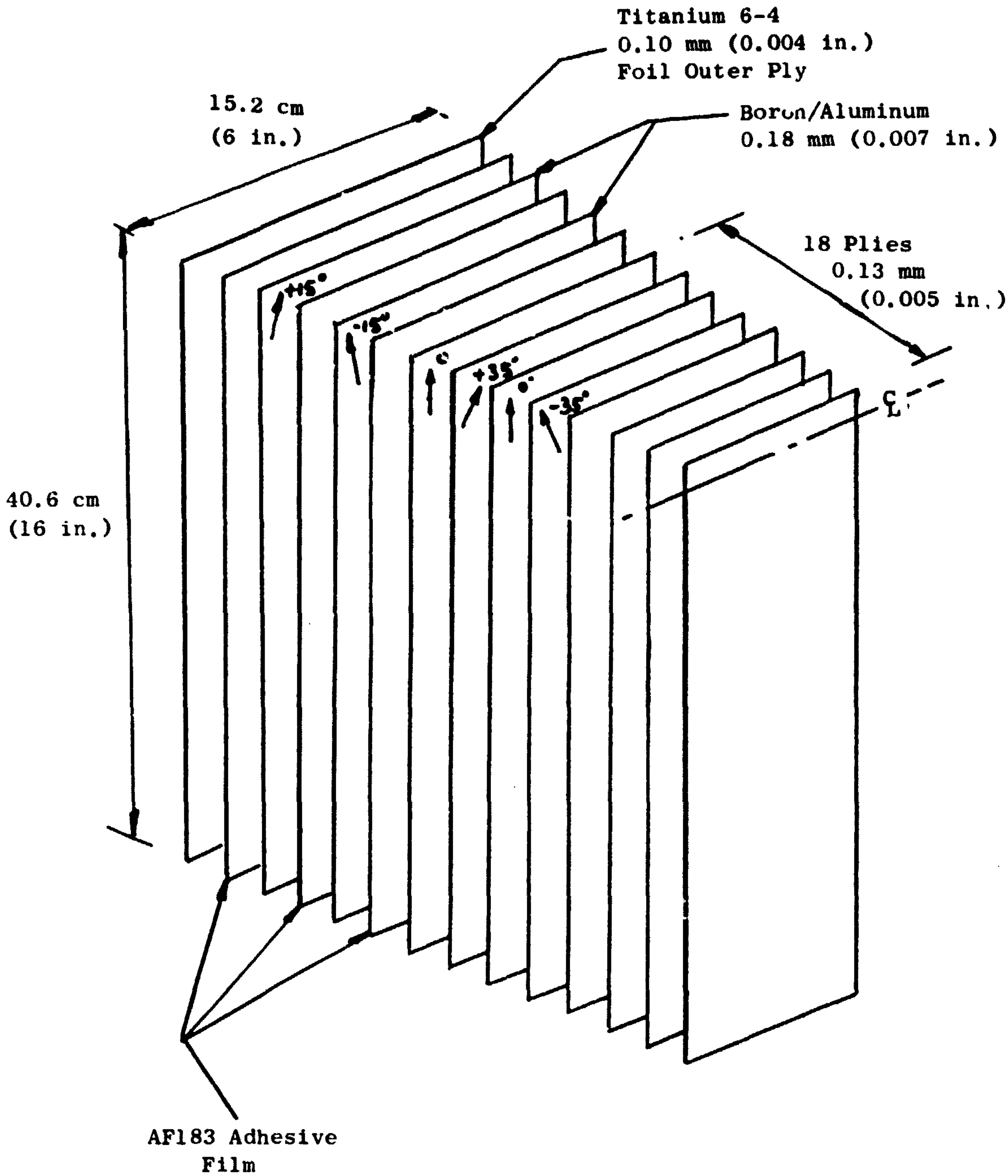


Figure 56. Superhybrid Design Specimen Material/Ply Orientation.

Superhybrid

Hybrid

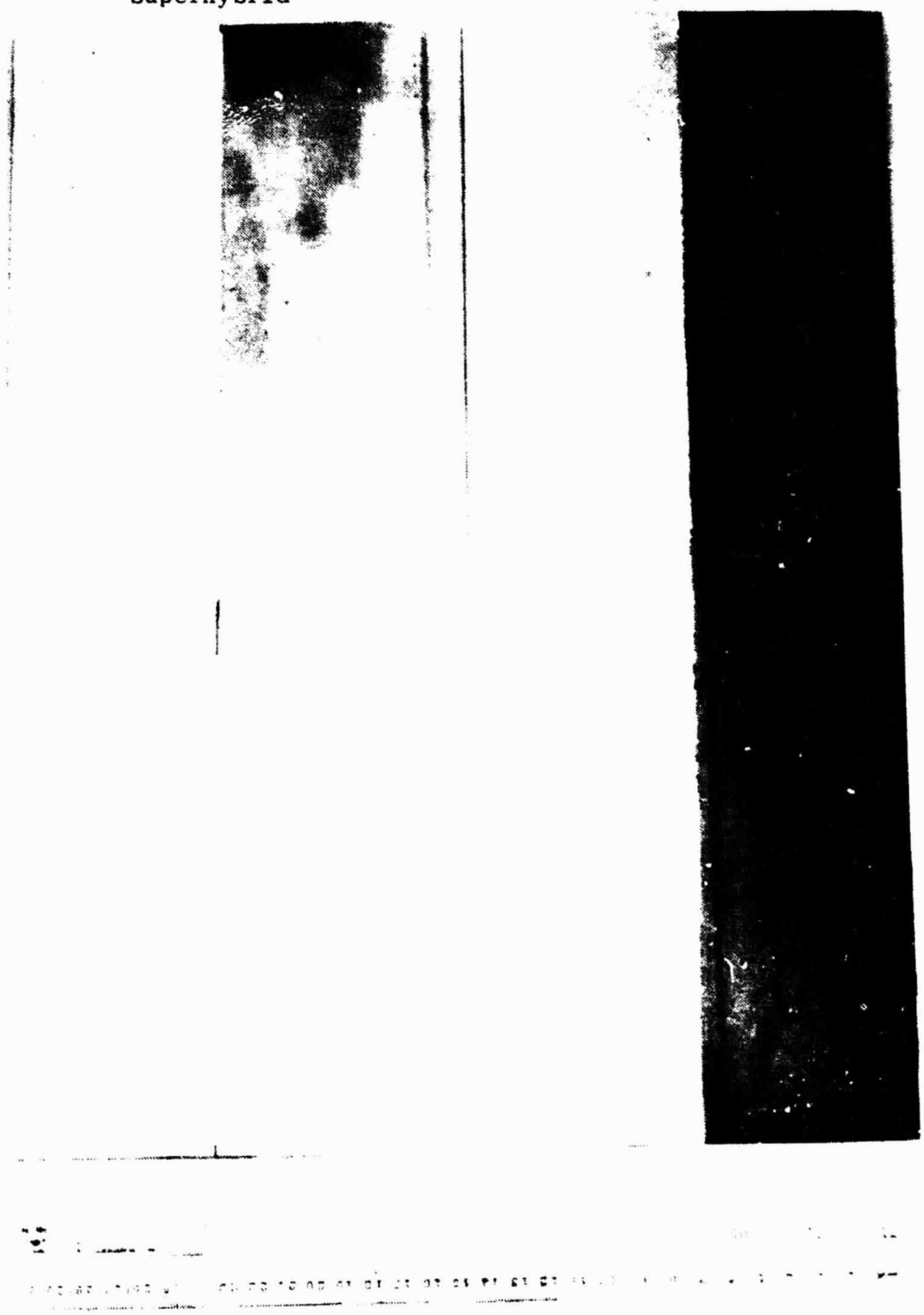


Figure 57. Typical Hybrid and Superhybrid Specimens.

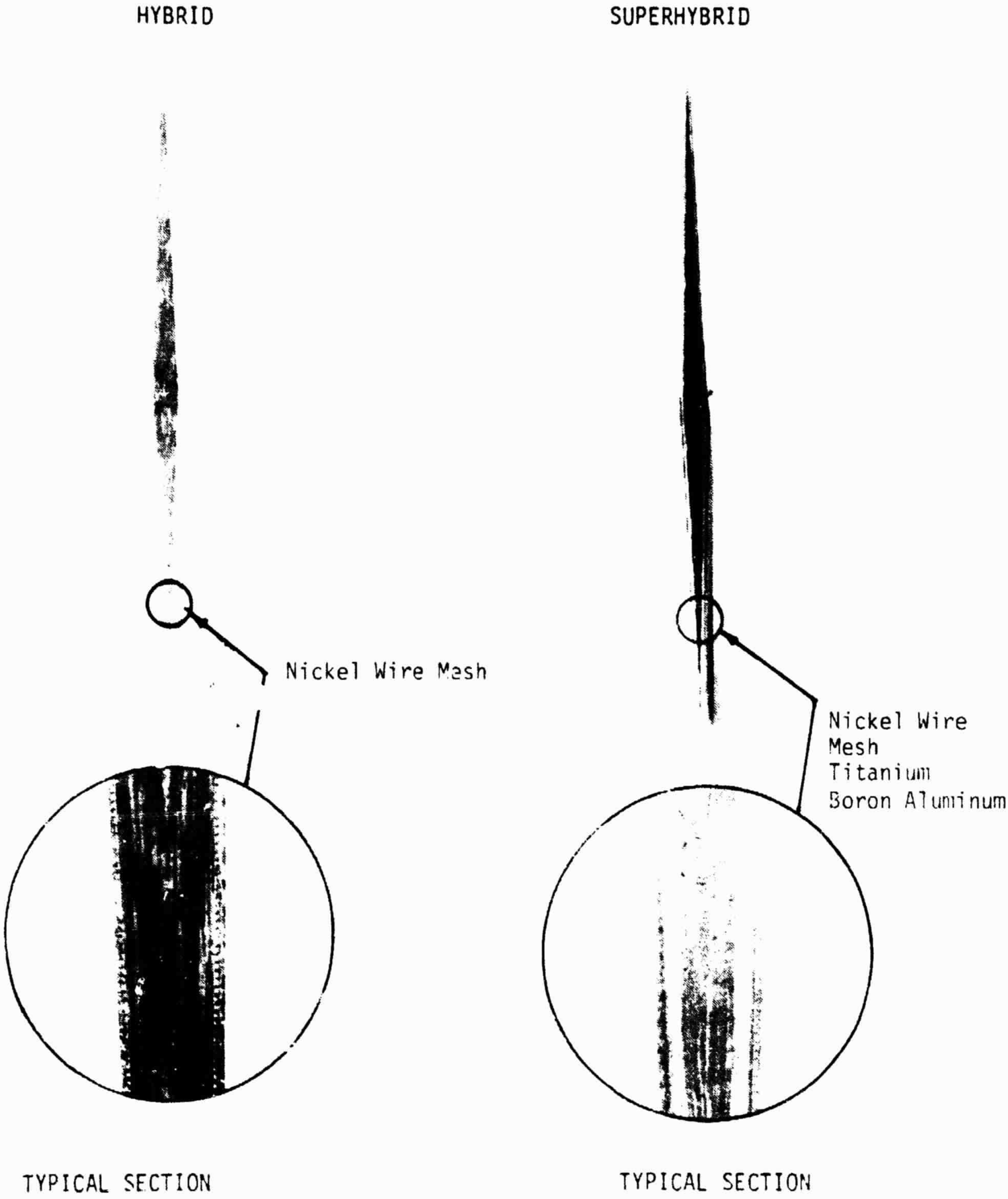


Figure 58. Typical Hybrid and Superhybrid Specimens.

Table LXXXIII. Q.C. Data Summary - Hybrid Prepreg (Specification 4013163-485).

Addendum ______

Prepreg Lot No. 814
Prepreg Type SP313/T300(80%)/S(20)
Quantity 13.27 kg(29.25 lbs) [600 ft]

Date Received 7-4-79
Expiration Date 4-4-80
Resin Batch No. Lot 647TP

		Vendor	MPTL	Spec.	Accept	Reject
A.	Graphite Data:					
	Batch No.	759-2/760-2				
	Tensile Str.,MPa(Ksi),Avg.	3033/3165	---	2827 Min.	X	
	Tensile Mod.,GPa(Msi),Avg.	221(230)		200-234	X	
	Density,gms/cc,Avg.	1,77/1.76		1.785-1.827		X
B.	Prepreg Data:			1.10 ± 4.0		
	Graphite, gms/m²(ft²)Avg.	103(9.57)	103(9.71)	(10.2±0.4)*		X
	Individ. Specimens***	1/3	1/4	2/3		X
	Sec.Fiber,gms/m²(ft²)Avg.	41(3.8)	38(3.56)	38±3.0(3.5±0.3)**	X	
	Individ.Specimens***	3/3	4/4	2/3	X	
	Tot. Fiber Wt.,gms/m²(ft²)Avg.	144(13.37)	143(13.27)	147±4.0(13.7±0.4)	X	
	Individ.Specimens***	2/3	2/4	2/3		
	Resin, gms/m²(ft²)Avg.	108(10.0)	90(8.35)	79±5.0(7.3±0.5)		X
	Individ.Specimens***	---	0/4	2/3		X
	Vols.,% wt.,Avg.	0.5	0.24	2% Max.	X	
	Individ.Specimens***	---	4/4	2/3	X	
	Gel Time,Mins.@ 383K(230°F)	---	N.A.(2)	40 Min.		
	Flow,%@ 383 K(230° F)	---	---	3 - 7		
	Visual Discrepancies					
C.	Laminate Data Panel No.	G-354	XP-3			
	Roll No.'s		---			
	Gel Time in Die,Mins.		---			
	Thickness, cm(in.)	4.9/Ply	0.085	0.080±0.002	X	
	Flex.Str.@RT,MPa(Ksi)	1593(231.0)	1517(220.0)	1345(195)	X	
	394 K(250°F),MPa(Ksi) (1)	1562(226.5)	1533(222.4)	1172(170)	X	
	Flex.Mod.@RT,GPa(Msi)	110(15.9)	102(14.8)	97(14.0)	X	
	394 K(250°F),GPa(Msi) (1)	105(15.2)	130(15.0)	90(13.0)	X	
	SBS Str.@RT,MPa(Ksi)	124(18.0)	111(16.1)	97(14.0)	X	
	394 K(250°F),MPa(Ksi) (1)	70.3(10.2)	82(11.9)	59(8.5)	X	
	Fiber Volume, %		55.3	48/12 (60±2) (3)		X
	Resin Content, % wt.		35.2	Report		
	Voids, %		0.36	2% Max.	X	
	Density, gms/cc	1.64	1.63	Report		

D. Material Disposition

Accept for all usage________________________. Reject ________ and (a) Return to

Vendor_______________or (b) Available for Limited Use Only NASA Environmental Program

Q.C. Eng. G.C. Murphy Date: 8-8-79

* Graphite wt. = 5.66 × SP. GR. of fiber
** Sec. Fiber Wt. = 1.42 × SP. GR. of fiber
*** No. Specimens in Spec./No. specimens tested
(1) at 450 K(350F) test temp.
(2) external gelation not typical of internal
(3) panel thickness oversize

Table LXXXIV. Q.C. Data Summary - Hybrid Prepreg (Specification 4013163-485).

Addendum ______

Prepreg Lot No. C9-480 — Date Received 7-13-79
Prepreg Type NR150A2/T300/S — Expiration Date ---
Quantity 10.25 kg(22.6 lbs) — Resin Batch No. E17602-7-1, E17602-7-2

	Vendor	MPTL	Spec.	Accept	Reject
A. Graphite Data:					
Batch No.	575-2				
Tensile Str.,MPa(Ksi),Avg.	3248(±71)		2827(410)Min.	X	
Tensile Mod.,GPa(Msi),Avg.	239(34.6)		200/234(29 - 34)	X	
Density,gms/cc,Avg.	1.75		1.785-1.827		X
B. Prepreg Data:					
Graphite, gms/m^2(ft^2)Avg.	102(9.5)	'102(9.515)	110±4.0(10.2±0.4)*		X
Individ. Specimens***		1/4	2/3		X
Sec.Fiber,gms/m^2(ft^2)Avg.	32(3.0)	30(2.828)	38±3.0(3.5±0.3)**		X
Individ. Specimens***	3	1/4	2.3		X
Tot. Fiber Wt.,gms/m^2(ft^2)Avg.	35(12.5)	133(12.343)	147±4.0(13.7±0.4)		X
Individ.Specimens***		2/4	2/3		
Resin, gms/m^2(ft^2)Avg.	75(7.0)	82(7.612)	79±5.0(7.3±0.5)	X	
Individ.Specimens***	3	4/4	2/3		
Vols.,% wt.,Avg.	18.4(1)	16.3	18% Max	X	
Individ.Specimens***	3	4/4	2/3		
Gel Time,Mins.@ 383 K(230° F)	1 (2)		40 Min.		
Flow,%@ 383 (230° F)			3 - 7		
Visual Discrepancies					
C. Laminate Data Panel No.		XNR-10			
Roll No.'s					
Gel Time in Die,Mins.					
Thickness, cm(in.)	0.079	0.080	0.080±0.002	X	
Flex.Str.@RT,MPa(Ksi)	1269(184)	1462(212)	1345(195)	X	
394 K(250°F),MPa(Ksi)	848(123)	1289(187)	1172(195)	X	
Flex.Mod.@RT,GPa(Msi)	99(14.3)	100(14.5)	97(14.0)	X	
394 K(250°F),GPa(Msi)	97(14.1)	101(14.7)	90(13.0)	X	
SBS Str.@RT,MPa(Ksi)	70(10.1)	97(14.0)	97(14.0)	X	
394 K(250°F),MPa(Ksi)	57(8.3)	77(11.2)	59(8.5)	X	
Fiber Volume, %		45/10	48/12 (60±2)		X
Resin Content, % wt.	28	38.2	Report		
Voids, %	4	-5.76	2% Max	X	
Density, gms/cc	1.4	1.686	Report		

D. Material Disposition

Accept for all usage________________. Reject__________ and (a) Return to Vendor __________ or (b) Available for Limited Use Only NASA Environmental Program

Q.C. Eng. G.C. Murphy Date: 8-8-79

* Graphite wt. = 5.66 × SP. GR. of fiber
** Sec. Fiber Wt. = 1.42 × SP. GR. of fiber
*** No. Specimens in Spec./No. specimens tested
(1) 1/2 Hr. at 589 K(600° F)
(2) at 478 K(400° F)

NR150 laminate was cut into two pieces and one piece was moisture saturated in a steam chamber to approximately one percent moisture weight gain while the other half was left in the fully dried condition. Each panel was "PreDoT" consolidate at 673 K (750° F) and 41.37 MPa (6,000 psi). The dry sample exhibited only minor plastic flow of the NR150A2 matrix but considerable extrusion and flow of the matrix was noted with the moisture conditioned specimen.

Initial conclusions regarding the "PreDoT" moisture effect phenomenon were:

- Moisture conditioning of cured NR150 laminates assist in "PreDoT" postforming by increasing thermoplastic flow of the matrix at lower processing temperatures and pressures. The effects of moisture on the mechanical properties of the matrix needs to be fully investigated.

- Moisture content of the basic NR150 prepregs may be a basic cause of batch to batch processing variables which are affecting industry acceptance of this material.

- Absorbed moisture may be detrimental to highly loaded NR150 components which operate at high temperatures. Sudden application of heat and load may cause thermoplastic flow (yielding) of the NR150 matrix.

The scaling up to a larger NR150 airfoil specimen presented problems in addition to the batch to batch variability.

After conducting panel molding trials with the new batch of material, the developed process was applied to the larger simulated airfoil specimens (6 in. chord x 16 in. long). Slight residual solvent retained within the thick center section of the preform (<1 percent average) created an unacceptable porosity zone during the 673 K (750° F) press molding cycle.

Four full size specimens were molded in an attempt to devise a satisfactory staging/cure/mold cycle. Preliminary indications were that oven staging the NR150 preform at 533 K (500° F) for >30 hours is necessary to remove all free solvent.

The molding/staging cycle finally developed for the NR150A2/T300/S hybrid Task III and IV airfoil specimens was as follows:

- <u>Staging Cycle</u>

The assembled preform was supported and lighly clamped in a contoured aluminum honeycomb fixture to allow easy release of volatiles. The assembly was placed in a cold oven and the temperature raised at 1.7 K (3° F)/minute to 394 K (250° F) and held at that temperature for one hour. The temperature

was raised at the same rate to 422 K (300° F) and held for 2 hours and again to 533 K (500° F) for 32 hours. Upon completion of the staging cycle ~1 percent solvent remained.

The solvent content was based upon adjacent material samples taken from prepreg roll and processed at 588 K (600° F) per the Q.C. solvent extraction method.

- <u>Molding Cycle</u>

The die temperature was raised to 588 K (600° F) and the preform was loaded and 6.89 MPa (1,000 psi) pressure slowly applied. The molding pressure was increased after 10-minute holding periods at each 6.89 MPa (1,000 psi) pressure increment until a maximum pressure of 31 MPa (4,500 psi) was reached. The mold was then allowed to cool to 394 K (250° F) prior to removal of the molding.

A total of twelve specimens were molded in accordance with the above procedure. The quality of the molding varied considerably despite the controlled processing. After evaluation of the NDE C-scanning inspection and visual inspection, a total of two moldings were scrapped. In view of the apparent success with repressing moisture conditioned specimens (Ref: Paragraph 5.2.1) the 10 potentially acceptable specimens were moisutre saturated and repressed at 616 K (650° F) in an attempt to improve the molding quality. An improvement in the NDE C-scan inspection was noted in all specimens, except two which exhibited excessive flow of material from the core during the repressing operation. The eight remaining specimens were approved for proceeding with the application of the wire mesh LE protection device.

During the bonding of the wire mesh to the NR150A2 hybrid specimens, a serious problem was uncovered. During the rework removal of the wire mesh off two specimens, which exhibited wrinkling of the wire, it was noted that the adhesion of the wire to the NR150 composite was good but that the outer layer of teh NR150 composite peeled away very easily as the wire was being stripped off. Moisture degradation of the NR150A2 matrix during the 588 K (650° F) pressing after moisture conditioning was suspected. A series of peel test specimens were produced by bonding wire mesh strips tp specimens which were moisture conditioned/press cured 588 K (650° F) and specimens which had not been subjected to moisture. Additional specimens were prepared in which the top layer of material had been removed in case the degradation was only superficial oxidation. Good adhesion with no laminate failure was apparent with the specimens which had not been moisture conditioned and molded at 588 K (650° F). All of the moisture conditioned specimens failed within the composite at minimal peel loads. All eight airfoil specimens had the bonded wire mesh removed and all exhibited similar matrix failure.

- <u>Effect of Moisture/Repressing of NR150A2</u>

In order to evaluate the moisture/processing effects on the composite mechanical properties, a NR150A2/T300/S test panel was fabricated using the staging/molding cycle employed for the Task III airfoil specimens. Half of the molded panel was subjected to the moisture conditioning and repressed at 616 K (650° F) and the remaining half panel was fully dried and not repressed.

The mechanical properties generated from test specimens machined from the two half panels are shown in Table LXXXV. The moisturized and repressed panel exhibits lower mechanical properties than the dry panel. A significant reduction in properties can be noted between the "dry" panel and the initial incoming Q.C. values recorded for this batch of material. Aging of the material and moisture absorption by the prepreg may be the cause of the lower properties.

5.2.2 Hybrid Specimens - (PMR15/T300/S)

In conjunction with NASA, PMR15 polyimide resin system was mutually selected to replace the problematic NR150A2 as the Tasks III and IV hybrid material.

5.2.2.1 Process Development

A total of 11 test panels were molded before an acceptable material quality control specimen was produced. The Q.C. Data Summary Sheet, Table LXXXVl shows the vendor (Fiberite Corporation) and in-house information generated on the basic prepreg and molded test panel.

The final process used in the fabrication of the 2 mm (0.080 in.) thick Q.C. test panel (PMR-11) was basically;

- Heat mold to 477 K (400° F)
- Place preform in mold and close mold down to 0.304 mm (0.012 in.) of closure,
- Hold for one hour (Imidize cycle),
- Remove panel from mold,
- Increase mold temperature to 588 K (600° F),
- Reload panel into hold mold and apply 6.9 MPa (1,000 psi),
- Hold for one hour at 588 K (600° F),
- Cool mold to below 533 K (500° F) and remove molding,
- Postcure ten hours at 588 K (600° F)
  Free in air-circulating oven.

The fundamental problems encountered during the process development of a satisfactory test panel were; 1) removal of excess matrix during the low viscosity stage of the resin imidizing cycle, 2) solvent removal from the compacted preform and 3) fiber wash during the molding cycle caused by the

Table LXXXV. NR150A2/T300/S Effect of Press Molding After Molding Conditioning.

Flexural/Flexural Strength/Modulus MPa(Psi) GPa(Msi)	Panel No. NR-OW ('"Dry")	Panel No. NR-1W One Percent Moisture	Incoming Q.C. Values MPa/GPa (Ksi/Msi)	Spec. Values MPa/GPa (Ksi/Msi)
R.T.	1043/82(151,230/11.85)	645/86(93,510/12.44)		
	1080/83(156,610/12.06)	658/86(95,500/12.45)		
	1140/88(165,340/12.70)	1011/85(146,600/12.26)		
	1097/86(159,050/12.43)	1350/84(195,760/12.21)		
Average	1090/85(158,057/12.26)	916/85(132,860/12.34)	1462/100(212/14.5)	1345/97(195/14)
394 K (250° F)	1147/85(166,290/12.29)	675/87(97,880/12.61)		
	1190/87(172,540/12.62)	912/81(132,340/11.77)		
	1156/87(167,590/12.63	1144/87(165,900/12.69)		
	1135/91(164,680/13.15	1231/85(178,510/12.39)		
Average	1157/87(167,780/12.67)	991/85(143,660/12.37)	1289/100(187/14.5)	1172/90(170/13)
Short Beam Shear Strength MPa(Psi)				
R.T.	91(13,150)	97(14,050)		
	94(13,580)	68(9,850)		
	96(13.940)	89(12,920)		
	95(13,800)	57(8,250)		
Average	94(13,620)	((11,270)	97(14)	97(14)
394 K (250° F)	63(9,150)	50(7,230)		
	64(9,290)	49(7,160)		
	68(9,880)	71(10,230)		
	71(10,350)	58(8,460)		
Average	67(9,670)	57(8,270)	77(11.2)	59(8.5)

C3

Table LXXXVI. Q.C. Data Summary - Hybrid Prepreg (Specification 4013163-485).

Addendum Class 'C'

Prepreg Lot No. C1-025
Prepreg Type PMR15/T300/S
Quantity 11.8 kg(26 lbs) (Two rolls)

Date Received 3-17-80
Expiration Date September, 1980
Resin Batch No. ------
Mfg. Date: 3/13/80

		Vendor	MPTL	Spec.	Accept	Reject
A.	Graphite Data:					
	Batch No.	1019				
	Tensile Str.,MPa(Ksi),Avg.	3268(474)	---	2827(410)Min.	X	
	Tensile Mod.,GPa(Msi),Avg.	234(34)	---	200-234 (29-34)	X	
	Density,gms/cc,Avg.	1.75	---	1.785-1.827		X
B.	Prepreg Data:			1.10 ± 4.0		
	Graphite, gms/m^2(ft^2)Avg.	105(9.80)	103(9.57)	(10.2±0.4)*		X
	Individ. Specimens***		---	2/3		
	Sec.Fiber,gms/m^2(ft^2)Avg.	33(3.02)	50(4.86)	38±3.0(3.5±0.3)**		X
	Individ.Specimens***	---	---	2/3		
	Tot. Fiber Wt.,gms/m^2(ft^2)Avg.	138(12.79)	153(14.25)	147±4.0(13.7±0.4)		X
	Individ.Specimens***	13	---	2/3		
	Resin, gms/m^2(ft^2)Avg.	83(7.7)	96(8.9)	79±5.0(7.3±0.5)		X
	Individ.Specimens***	13	---	2/3		
	Vols.,% wt.,Avg.	103(9.6)	81(7.52)	Report	X	
	Individ.Specimens***	3	---	2/3		
	Gel Time,Mins.@473K(400°F)	0.8	---	Report	X	
	Flow,%@450K(350°F)69MPa(100 psi)	19.7	---	Report	X	
	Visual Discrepancies					
C.	Laminate Data Panel No.					
	Roll No.'s		1			
	Gel Time in Die,Mins.		---			
	Thickness, mm(in.)	2.2(0.088)	0.2(0.075)	0.080±0.002		X
	Flex.Str.@RT,MPa(Ksi)	1145(166)	1510(219)	1345(195)	X	
	@394 K (250°F),MPa(Ksi)	1124(163)	1613(234)	1172(170)	X	
	Flex.Mod.@RT,GPa(Msi)	87(12.48)	116(16.85)	97(14.0)	X	
	394 K(250°F),GPa(Msi)	89(12.89)	121(17.5)	90(13.0)	X	
	SBS Str.@RT,MPa(Ksi)	105(15.2)	109(15.8)	97(14.0)	X	
	394 K(250°F),MPa(Ksi)	88(12.8)	95(13.8)	59(8.5)	X	
	Fiber Volume, %	---	59.83	48/12 (60±2)	X	
	Resin Content, % wt.	38.2	28.74	Report		
	Voids, %	---	5.27	2% Max.		X
	Density, gms/cc	0.58		Report		
	Ply Thickness (ins)	0.0055				

D. Material Disposition

Accept for all usage__________. Reject________ and (a) Return to

Vendor________ or (b) Available for Limited Use Only NASA Environmental Program

Q.C. Eng. G.C. Murphy Date: April, 1980

* Graphite wt. = 5.66 × SP. GR. of fiber
** Sec. Fiber Wt. = 1.42 × SP. GR. of fiber
*** No. Specimens in Spec./No. specimens tested

"Plastic" flow of the viscous imidized resin. A complete list of the process development 7.62 cm x 17.78 cm x 2 mm (3 in. x 7 in. x 0.080 in.) panels produced are shown in Table LXXXVII.

5.2.2.2 PMR15 Hybrid Specimen Fabrication

Considerable difficulties were encountered in scaling up the PMR15/T300/S flat panel process to the 40.6 cm x 15.24 (16 in. long x 6 in.) chord simulated airfoil specimen size. The fundamental problems exhibited in the flat panel process were further complicated by the variation in the "airfoil" thickness 1.27 mm to 6.3 mm (0.050" in. to 0.250 in.). Fiber "wash" during final molding and excess resin loss due to the rapid expulsion of the solvent at the 477 K (400° F) imidizing temperature were the major concerns. The goal was to achieve a relatively fast economic process cycle which could be applied to future blade and vane production. Slow imidizing cycles and long press molding procedures were, however, evaluated without any improvement being noted in the molded part. The list of specimens fabricated during the attempts to develop a satisfactory process are shown in Table LXXXVIII. Panels PMR-F8, F9 and F10 were fabricated using surplus PMR/T300 prepreg since the PMR15/T300/S available material stock was diminishing rapidly. Panel F3, which exhibited two local blistered areas, was also subjected to a 12 hour room temperature water soak and repressed at 588 K (600° F) to evaluate the "NR150 moisture plasticizing/increased flow effect". The C-scan re-evaluation of the part indicated considerably more delamination occurred as a result of the moisture treatment. The process initially evaluated on F3 panel appeared to exhibit the best visual quality and C-scan indications of minimum porosity and, therefore, Panels F10 and F11 were successfully repeated using the same basic process except the initial die closing time was extended to 15 minutes to allow improved venting of the solvent prior to imidizing for an additional one hour.

All the remaining Task III and IV specimens were fabricated using this process and are listed in Table LXXXIX. A large percentage of the specimen exhibit slight leading/trailing edge damage caused by resin/fiber flash entrapment between the punch and cavity of the mold being broken off while opening the mold after cooling down to 533 K (500° F).

- Postcure Study

Prior to selecting the postcuring procedure for the large FOD test specimens, sample test panels 7.62 cm x 17.78 x 2.03 mm (3 in. x 7 in. x 0.080 in.) molded in accordance with the method developed for the FOD specimens, were fabricated and then postcured. One sample test panel was cut into two pieces and one piece postcured by placing into an oven at room temperature and raising to 588 K (600° F) at 5.6 K (10° F)/minute and held for 10 hours. The panel exhibited severe surface blistering. The second half of the panel was subjected to a postcure cycle consisting of 449 K (350° F) for 72 hours followed by a 588 K (600° F) for 10 hours using a similar heatup rate as the previous panel. No blistering was evident in the panel indicating that the free methanol, believed to be the cause of the blistering , had been removed by

Table LXXXVII. Process Development Panels - PMR15/T300/S.

Specimen No.	Preform Wt. (GMS)	Imidizing Cycle	Wt. After Imidizing (GMS)	Molding Cycle	Final Wt. (GMS)	Avg. Max. Molded Thickness mm (in.)	Comments
PMR-1	57.30	477 K (400° F) for 1 hour with 1mm (0.040 in.) shims	---	477 K (400° F) - 505 K (450° F) 505 K (450° F). Apply 500 psi Increase temp. to 589 K (600° F) for 1 hour	42.0	2.16 (0.085)	0.127 mm (0.005 in.) Oversize voids each end
PMR-2	57.30	Imidize in oven for 16 hours @ 477 K (400° F)	---	RT -527 K (490° F). Apply 17 MPa (2500 psi) 527 K (490° F) -589 K (600° F). Hold for 2 hours	52.5	2.44 (0.096)	0.508 mm (0.020 in.) Oversize fibers poorly bonded
PMR-3	56.10	477 K (400° F) in press for 1 hour with 1 mm (0.040 in.) shims	NA	477 K (400° F) - 589 K (600° F) with 34 MPa (5000 psi)	47.0	2.06 (0.081)	Fiber extrusion High porosity in glass fibers
PMR-4	55.94	477 K (400° F) for 1 hour with 0.7 mm (0.030 in.) shims	NA	Increase pressure to 5.5MPa (800 psi). Temp. 477 K (400° F) - 589 K (600° F) hold 1 hour	47.5	2.06 (0.081)	Fiber extrusion one end
PMR-5	56.42	477 K (400° F) for 1 hour with 0.76 mm (0.030 in.) shims	---	Trim to add Viton rubber on each end. 505 K (450° F) 589 K (600° F) with 5.5 MPa (800 psi). Hold one 1 hour	43.0	2.13 (0.084)	0.127 mm (0.005 in.) Oversize Wrinkle fibers. Viton rubber at each end to seal die.
PMR-6	55.93	477 K (400° F) for 1 hour with 2 mm (0.080 in.) shims	NA	477 K (400° F - 589 K (600° F) with 5.5 MPa (800 psi). Hold 589° K (600° F) for 1 hour	38.0	2.01 (0.079)	Large resin loss High percentage of voids/ porosity
PMR-7	56.10	477 K (400° F) for 1 hour with 2 mm (0.080 in.) shims	NA	477 K (400° F) - 589 K (600° F) with 5.5 MPa (800 psi). Hold 589° K (600° F) for 1 hour	43.0	2.01 (0.079)	High percentage of voids/ porosity
PMR-8	55.62	394 K (250° F) with 0.76 mm (0.030 in.) shims for 1 hour	NA	394 K (250° F) - 505 K (450° F) Increase pressure to 5.5 MPa (800 psi). 505 K (450° F) 589 K (600° F). Hold 589 K (600° F) for 1 hour	43.0	2.01 (0.079)	Large resin loss High percentage of voids/ porosity
PMR-9	56.25	366 K (200° F) for one 1 hour with 0.38 mm (0.015 in.)	NA	366 K (200° F - 505K (450° F) Apply 5.5 MPa (800 psi) 505 K (450° F) - 589 K (600° F). Hold for 1 hour.	44.5	2.01 (0.079)	High percentage of voids/ porosity
PMR-10	55.54	477K (400° F) - 1 mm (0.040 in.) shims for 1 hour	---	Remove from mold, preheat 589 K (600° F). Place in 589 K (600° F) mold with 5.5MPa (800 psi). Hold 1 hour	48.0	2.24	0.203 mm (0.008 in.) Oversize Good Appearance
PMR-11	55.03	477 K (400° F) - 0.30 mm (0.012 in.) shims for 1 hour	42.78	Remove preheat mold to 589K (600° F) and 6.9 MPa (1000 psi). Hold for one hour. [Post cure 10 hours @ 589 K (600° F)]	42.56	1.90 (0.075)	0.127 mm (0.005 in.) Undersize Good apearance
PMR-12	55.12	477 K (400° F) - 0.89 mm (0.035) in.) shims for 1 hour	47.29	Remove and preheat mold to 589 K (600° F) Hold with 1.10 MPa (1600 psi) for one hour	47.28	2.16	0.127 mm (0.005 in.) Oversize Blisters during post cure

Table LXXXVIII. Process Development PMR-15 FOD Test Panels.

Specimen No.	Preform Wt. (GMS)	Imidizing Cycle	Wt. After Imidizing (GMS)	Molding Cycle	Final Wt. (GMS)	Avg. Max. Molded Thickness mm (in.)	Comments
PMR-F1	452	1 hour @ 477 K (400° F) with 0.89 mm (0.035 in.) shims.	408	Place in 589 K (600° F) mold with 11.03 MPa (1600 psi)	404	6.60 (0.260)	Fiber wash top surface 0.254 mm (0.010 in.) Oversize
PMR-F2	452	1 hour @ 477 K (400° F) with 0.635 mm (0.024 in.) shims.	402	589 K (600° F) with 11.03 MPa (1600 psi)	399	6.30 (2.48)	Excess Fiber wash
PMR-F3	445	1 hour @ 477 K (400° F) with 0.635 mm (0.025 in.) shims. Slow close over last 0.035 mm (0.025 in.) [11 min.]	411	589 K (600° F) with 11.03 MPa (1600 psi).	406	6.45 (254)	No fiber wash. 0.254 mm to 0.015 Oversize. Two (2) blister areas indicated on "C" scan. 0.127 mm (0.0025 in.)/ply layup.
PMR-F4	440	1 hour @ 477 K (400° F) 0.635 mm (0.025 in.) shims Slow close over last 3.81 mm (0.150 in.) [3 min. period].	399	589 K (600° F) with 11.03 MPa (1600 psi)	396	6.65	0.127 mm (0.005 in.) Oversize.0.127 Fiber wash. 0.127 mm (0.005 in.)/ ply layup
PMR-F5	401	Start @ 399 K (150° F) [0.635 mm (0.025 in.) shims]. Slow close. Oversize 6.35 mm (0.250 in.) in 15 min. Raise temp. 0.56 K/min (1° F)/min to 477 K (400° F). Hold 1 hour	NA	Raise temperature to 589 K (600° F). Hold for 3 hours with 10.34 MPa (1500 psi)	342	5.99 (0.2360	20 Gms. of extruded resin. 0.135 mm (0.0054 in.)/ply layup
PMR-F6	403	399-477 K (150-400° F) @ 1 K per min. Slow close over 15 min.	NA	Raise temperature to 589 K (600° F). Increased pressure 533 K (500° F) to 6.895 MPa (1000 psi)	367	6.12 (0.241)	0.135 mm (0.0054 in.)/ply layup
PMR-F7	430	339-477 K (150-400° F) @ 0.39 K (0.7° F)/ with 100% Oversize shims.	NA	477-530 K (400° F-495° F0, increase pressure to 6.89 MPa (1000 psi) temperature 530 K (495° F) - 589 K (600° F) Hold 13 hours.	387	6.60 (0.260)	0.259 mm (0.010.) Oversize Blisters 0.135 mm (0.0054 in.)/ ply layup
PMR-F8	365	Repeat Process PMR-F7	NA	Repeat process PMR-F7	340	6.07 (0.239)	Wrinkled PMR/T300 Material, Lot 11320
PMR-F9	405	477 K (400° F) with 6.35 mm (0.250 in.) shims for 15 mins. Remove 0.635 mm (0.025 in.) shims. Close to 0.889 (0.035 in.). Hold 1 hour.	374	Remove and Preheat mold to 589 K (600° F) Replace part 589 K (600° F) with 11.03 MPa (1600 psi). Hold 1 hour.	371	6.73 (0.265)	PMR/T300 Material
PMR-F10	401	1 hour @ 477 K (400° F) 0.635 mm (0.025 in.) shims. Slow close over last 6.36 mm (0.250 in.) [15 min.]	365	589 K (600° F) with 11.03 MPa (1600 psi)	364	6.07 (0.239)	PMR/T300 Material. Small area of porosity indicated on "C"-scan.
PMR-F11	441	2 hour @ 477 K (400° F) 0.635 mm (0.025 in.) shims Slow close over last 0.635 mm (0.025 in.) [15 min].	407	589 K (600° F) with 11.03 MPa (1600 psi)	406	6.38 (0.251)	Minimal porosity indications on "C"-scan 0.127 mm (0.005 in.)/ ply layup.
PMR-F12	403	2 hours @ 477 K (400° F) 0.635 mm (0.025 in.) shims. Slow close over last 0.635 mm (0.025 in.) [15 min]	371	589 K (600° F) with 11.03 MPa (1600 psi)	370	0.245 (0.099)	Scrapped (during wire saw operation)

Table LXXXIX. Task III and IV PMR Test Specimen Data.

S/N	Perform Weight (gms)	Weight After Imidizing (gms)	Final Molded Weight (gms)	Molded Thickness mm(in.)	Density (gms/cc)	Visual Defects
F12*	403	371	370	6.22 (0.245)	1.5837	4 Hour imidize cause porosity; slight edge damaged
F13	406	376	375	6.27	1.5805	Slight edge porous; surface ripples; small fiber wrinkle
F14*	305	375	374	6.27 (0.247)	1.5855	Slight fiber tow unbond one edge
F15*	406	375	374	6.27 (0.247)	1.5855	One side porous + dry; surface ripples
F16*	407	375	375	6.27 (0.247)	1.5855	Slight edge damaged; surface ripple
F17*	397	367	367	6.20 (0.244)	1.5808	Slight edge damaged; slight surface ripple
F18	395	365	364	6.20 (0.244)	1.5808	Rough surface texture - bad flow
F19*	395	365	364	6.20 (0.244)	1.5808	Slight surface ripple
F20*	395	364	364	6.17 (0.243)	1.5947	Edge damage both sides; slight surface ripple
F22*	395	365	364	6.17 (0.243)	1.5808	No apparent defects
F23*	395	365	365	6.17 (0.243)	1.5852	Slight edge damaged; slight surface ripple
F24*	394	364	364	6.17 (0.243)	1.5833	Slight edge damaged; slight surface ripple
F25*	401	371	370	6.25 (0.246)	1.5844	Edge damage boh sides; surface ripples
F26*	403	372	371	6.22 (0.245)	1.5819	Edge damage both sides; surface ripples
F27*	403	371	371	6.25 (0.246)	1.5870	Slight surface ripple

diffusion at the lower temperature. In order to evaluate the effects (or need) of the postcure cycle, two panels were fabricated for mechanical properties determination. The effects of no postcure were evaluated with Panel No. 14, and Panel No. 15 was cut into two pieces, one half was postcured for 20 hours at 450 K (350° F). The results are tabulated in Table XC. Although additional post curing after press molding does not appear to improve mechanical properties [up to 394 K (250° F)], all the FOD test specimens were subjected to additional "postcuring" at 449 K (350° F) to remove any free solvent.

5.2.3 Superhybrid Specimens

A total of fourteen (10 Task III and 4 Task IV) superhybrid specimens were fabricated using the fiber orientation/layup design shown in Figure 56. The surface preparation of the Titanium 6-4 and the boron/aluminum foils consisted of light grit blasting using 120 alumina grit and 0.4 MPa (20 psi) pressure and apply a 3M primer PA-3917. After air drying the primer for 2 hours at room temperature, a film of AF-147 3M adhesive was applied to the bonding surface in accordance with the ply stacking sequence shown in Figure 56. The assembled preform was placed into the preheated mold tool [422 K (300° F]. The mold was closed at a predetermined closure rate using a maximum pressure of 5.17 MPa (750 psi). The part remained in the die under pressure and temperature for 2 hours. Immediately upon removal from the mold, the specimen was transferred to the postcure oven operating at 450 K (350° F) for four (4) hours. The specimens were subjected to NDE C-scan inspection prior to applying the nickel plated leading edge protection device. NDE C-scan equipment parameters were established to determine more realistic "defect indications". The first eight specimens C-scanned indicated that varying degrees of porosity existed within the composite core section of each specimen. The differing gelation times, at the molding temperature, of the AF147 Adhesive film and the SP313 core laminating resin, in addition to high volumeric squeeze out of the AF147 [0.29/m^2 (0.06 lb/ft^2)] adhesive were believed to be the cause of the varying porosity. Although each specimen has been processed using the die closure time/distance curve, slight immeasurable deviations created porosity within the core laminations. Relatively fast die closure rates were required to expell the surplus adhesive between the metallic foils prior to the gelation of the AF147 which affected the retention of the SP313 core matrix. Nonstandard lower weight adhesive films with extended gelation times would rectify the problem for future similar design specimens.

The manufacturing data including the nickel plated wire mesh inspection records for the 14 superhybrid specimens are shown in Table XCII

5.3 LEADING EDGE PROTECTION SYSTEM

A leading edge protection system comprising of a 0.254 mm (0.010 in.) 314 stainless steel foil bonded with a unique polyurethane elastomeric adhesive system was considered as an alternate to the nickel plated wire mesh system developed by General Electric (U.S. Patent No. 3892612 - Method for Fabricating Foreign Object Damage Protection for Rotor Blades).

Table XC. Effect of Postcure on Properties of PMR15/T300/S Laminates.

Property	Fiberite QC Data 10 Hours @ 589 K (600° F)	MPTL QC Data 10 Hours @ 450 K (350° F)	PMR No. 14 No Post Cure	PMR No. 15 450 K (350° F) For 20 Hours	PMR No. 15 450K(350°F) For 20 Hours @ 589 K (600° F) For 10 Hours
Flexural Strength MPa(Ksi)					
294 K (70° F)	1145(166)	1510(219)	1351(196)	---	---
394 K (250° F)	1123(163)	1613(234)	1248(181)	1324(192)	1338(194)
Flexural Modulus MPa(Msi)					
294 K (70° F)	86(12.58)	116(16.85)	95(13.82)	---	---
394 K (250° F)	88(12.89)	121(17.5)	96(13.85)	96(13.97)	98(14.2)
Short Beam Shear MPa(Ksi)					
294 K (70° F)	105(15.2)	109(15.8)	96(13.9)	---	---
589 K (600° F)	88(12.8)	95(13.8)	83(12.0)	87(12.6)	90(13.0)
Fiber Volume Percent	---	59.83	50.0	---	---
Void Content Percent	---	5.03	0.17	---	---
Panel Thickness mm/(in.)	2.2(0.088)	1.9(0.075)	2.1(0.082)	2.15(0.085)	2.15(0.085)

Table XCI. Tasks III and IV Hybrid Specimen Manufacturing Data.

Specimen No.	Final Wt. (gms)	Max. Thickness mm(in.)	Leading Edge Protection		
			Total Wt. (gms)	Dimension X mm(in.)	Dimension Y mm(in.)
PMR F-13	610	6.25(0.246)	0.245	0.584(0.023)	1.96(0.077)
PMR F-14	581	6.22(0.245)	0.229	0.432(0.017)	1.85(0.073)
PMR F-15	612	6.22(0.245)	0.247	0.559(0.022)	2.41(0.095)
PMR F-16	616	6.25(0.246)	0.241	0.584(0.023)	2.24(0.088)
PMR F-17	615	6.20(0.244)	0.273	0.559(0.022)	2.08(0.082)
PMR F-19	579	6.17(0.243)	0.221	0.432(0.017)	1.80(0.071)
PMR F-20	606	6.17(0.243)	0.258	0.508(0.020)	2.06(0.081)
PMR F-21	606	6.15(0.242)	0.259	0.508(0.020)	2.06(0.081)
PMR F-22	584	6.15(0.242)	0.227	0.559(0.022)	1.88(0.074)
PMR F-23	604	6.15(0.242)	0.255	0.483(0.019)	2.31(0.091)
PMR F-24	656	6.17(0.243)	0.304	0.635(0.025)	2.54(0.100)
PMR F-25	573	6.20(0.244)	0.224	0.483(0.019)	1.90(0.075)
PMR F-26	589	6.17(0.243)	0.240	0.559(0.022)	1.73(0.068)
PMR F-27	601	6.20(0.244)	0.255	0.584(0.023)	2.36(0.093)

Table XCII. Tasks III and IV Superhybrid Specimen Manufacturing Data.

Specimen No.	Final Wt. (gms)	Max. Thickness mm(in.)	Leading Edge Protection		
			Total Wt. (gms)	Dimension X mm(in.)	Dimension Y mm(in.)
SPIII-1	725	6.25(0.246)	0.289	0.553(0.021)	1.96(0.077)
SPIII-2	706	6.17(0.243)	0.279	0.584(0.023)	2.08(0.082)
SPIII-3	671	6.40(0.252)	0.213	0.432(0.017)	1.60(0.063)
SPIII-4	716	6.22(0.245)	0.264	0.553(0.021)	1.98(0.078)
SPIII-5	695	6.40(0.252)	0.247	0.457(0.018)	1.80(0.071)
SPIII-6	627	6.38(0.251)	0.158	0.457(0.018)	1.57(0.062)
SPIII-7	719	6.48(0.255)	0.259	0.432(0.017)	1.70(0.067)
SPIII-8	681	6.10(0.240)	0.198	0.432(0.017)	1.80(0.071)
SPIII-9	763	6.35(0.250)	0.306	0.610(0.024)	2.13(0.084)
SPIII-10	711	6.43(0.253)	0.254	0.483(0.019)	1.70(0.067)
SPIII-11	720	6.38(0.251)	0.263	0.610(0.024)	2.36(0.093)
SPIII-12	711	6.38(0.251)	0.247	0.559(0.022)	1.88(0.074)
SPIII-13	726	6.45(0.254)	0.258	0.559(0.022)	2.31(0.091)
SPIII-14	627	6.40(0.252)	0.157	0.330)0.013)	1.52(0.060)

Initial ballistic impact evaluation of the alternative system on the Air Force F103 Blade Program (F33615-74-C-5072) appeared promising. A typical F103 blade midspan FOD airfoil section specimen sustained a total of eight impacts of 108 gms (3.8 oz.) simulated bird at varying velocities up to 335 m/sec (1100 ft/sec). Although considerable deformation of the leading edge occurred during the tests, the steel foil remained bonded to the composite. Prior to committing to the use of the new protection device for Tasks III and IV, a preliminary moisture/temperature capability study of the polyurethane film adhesive was conducted. Aluminum single lap shear test specimens were fabricated using the 3M polyurenthane film 0.152 mm (0.006 in.) modified with the thermoset adhesive PR288. Fifty percent of the specimens were wet conditioned by immersing in water 355 K (180° F) for 4 days. The significant reduction in properties, illustrated in Figure 59, caused by temperature and moisture, negated the use of this system for Tasks III and IV and, therefore, all the specimens were fitted with the originally selected nickel plated wire mesh as the protection device.

5.3.1 Nickel Plated Wire Mesh Leading Edge Protection System

The selected nickel plated wire mesh protection device basically consists of an annealed 316 stainless steel 100 mesh wire cloth secondary bonded to the leading edge of the molded specimen using Metlbond 328 (NARMCO) GE Spec. A50TF104-Class C adhesive. The surplus cured adhesive is removed from the external surface of the wire cloth until the wire is completely exposed. The wire surface is electroplated using a sulfamate nickel plating solution to the thickness shown in Figure 54. The varying thickness/contour of the nickel plate is achieved by the use of "thieves" and shielding built into the plating fixture. After plating, the leading edge contour is benched to final dimensions.

Two prototype specimens were processed by Hohman Plating, Dayton to establish the plating procedures and to ensure a satisfactory quality level. Plating hardness inspection on the two specimens exhibited hardness values of Rockwell C31.5 and C32.5 respectively which was well within the General Electric plating specification limits (GE Spec. 4013192-654).

The fabrication data records for the plated and finished specimens are shown in Table XCI Hybrid Specimens and Table XCII Superhybrid Specimens.

5.4 SPECIMEN MOISTURE CONDITIONING

The completed specimens were subjected to a quality review by Design and Manufacturing personnel and allocated to specific tests. Table XCIII shows the test matrix/specimen allocation for Task III specimens and Table XCIV, the Task IV Plan.

The Task III specimens were supplied to Cincinnati Test Laboratories for moisture conditioning together with three additional calibration specimens to determine moisture saturation parameters. A basic PMR/T300/S molding with no

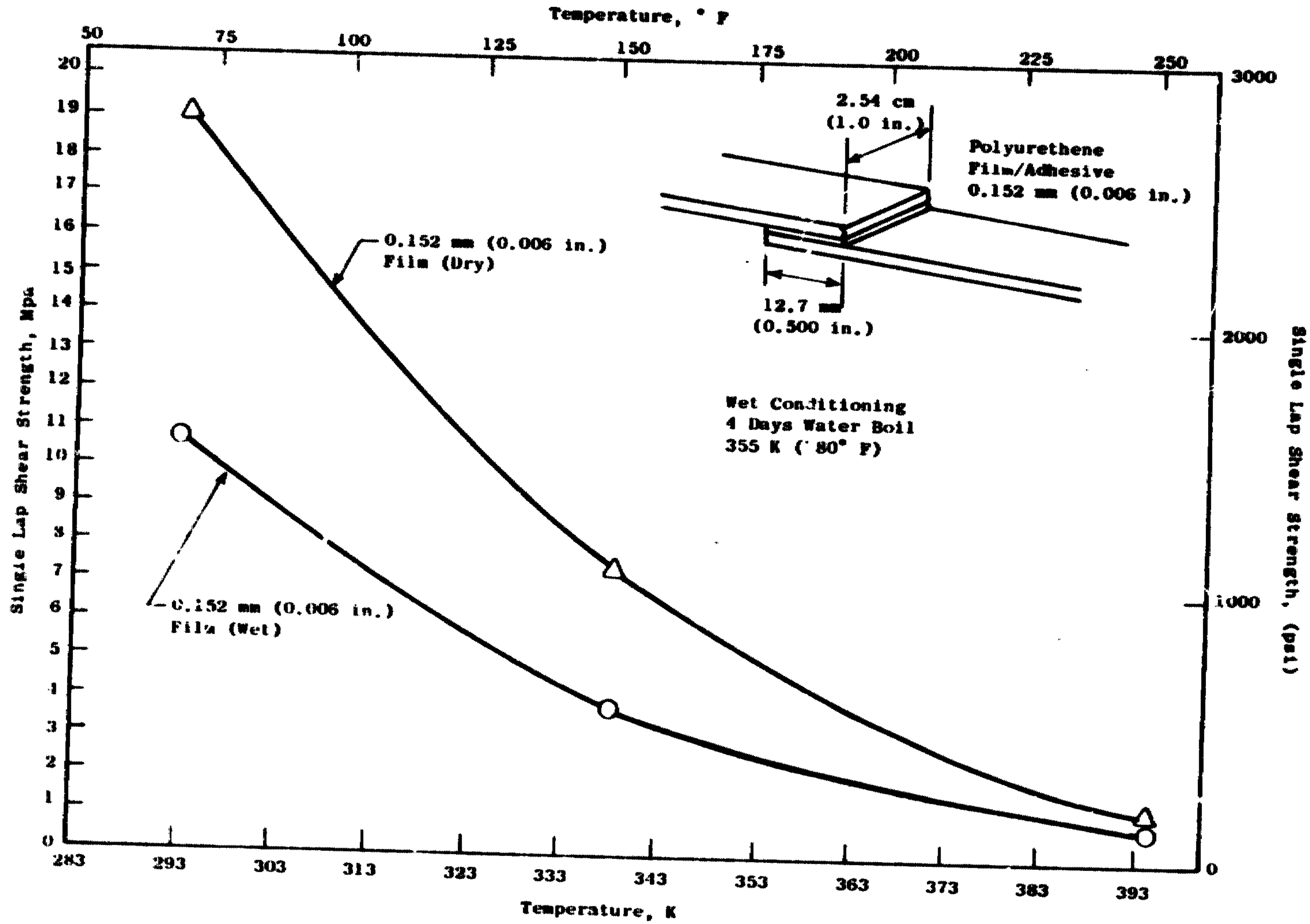


Figure 59. Lap Shear Test Results 3M Polyurethane Film/PR288 Adhesive.

Table XCIII. Test Matrix/Specimen Allocation, Task III - Static Tests.

Specimen Design (Material)	Test Temperature Condition				
	219 K (-65° F) Dry	294 K (70° F) Dry	394 K (250° F) Wet	394 K (250° F) Dry	394 K (70° K) Wet
Superhybrid (SP313)	S/N SPIII-1 S/N SPIII-7	S/N SPIII-2 S/N SPIII-9	S/N SPIII-5 S/N SPIII-8	S/N SPIII-3 S/N SPIII-10	S/N SPIII-11 S/N SPIII-13
Hybrid (PMR15)	S/N PMRF-13 S/N PMRF-20	S/N PMRF-15 S/N PMRF-21	S/N PMRF-16 S/N PMRF-17	S/N PMRF-19 S/N PMRF-22	S/N PMRF-26 S/N PMRF-27

Table XCIV. Test Matrix/Speciment Allocation, Task IV - Whirligig Tests

(Specimens Fitted With Titanium Adaptors)

Specimen Design(Material)	Test Temperature Condition	
	294 K (70° F)	394 K (250° F)
Superhybrid (SP313)	S/N SPIII-4 S/N SPIII-12	S/N SPIII-6 S/N SPIII-14
Hybrid (PMR15)	S/N PMRF-23 S/N PMRF-24	S/N PMRF-14 S/N PMRF-25

protection (S/N PMR-F2) was conditioned at 355 K (180° F)/97% RH to determine the fully saturated "wet" and "wet spike" time scale for all specimens and a similar specimen fabricated using PR288/AS/S material (S/N PRIII-2) was employed to determine the "dry" conditioning parameters. A third specimen constructed of PR288/AS/S material with leading edge protection was included for comparison. The basic conditioning plan and procedures for the Task III "wet" specimens was as follows:

- Dry all specimens for 24 hours at 394 K (250° F)
- Record specimen weight
- Condition all Task III "wet" specimens and the three calibration specimens at 355 K (180° F)/97% RH
- Monitor weight gain percentage and graphically plot against time (days) for each calibration specimen and one of each design test specimen
- "Saturation" time was determined by the levelling out of the curve for the PMR15 (no LE protection) specimen. (S/N PMR-F2) - Ref: Figure 60 - Conditioning parameters for Tasks III and IV specimens
- Remove specimens on the day of test (>X days)
- Record moisture percentage weight gain
- Conduct torsional rigidity inspection. Determine load required to twist specimen through an angular displacement of 2 degrees
- Specimens wrapped tightly in aluminum foil and passed to the University of Dayton for impact testing.

The "dry" moisture conditioning procedure for the Task III specimens was:

- Dry all specimens for 24 hours at 394 K (250° F),
- Record specimen weight,
- Condition "dry" specimens at 355 K (180° F)/97% RH for y days ±2 hours (Ref: Figure 60),
- Record Moisture percentage weight gain,
- Conduct torsional rigidity inspection. Determine load required to twist specimen through an angular displacement of 2 degrees,
- Specimens wrapped tightly in aluminum foil and passed to the University of Dayton for impact testing.

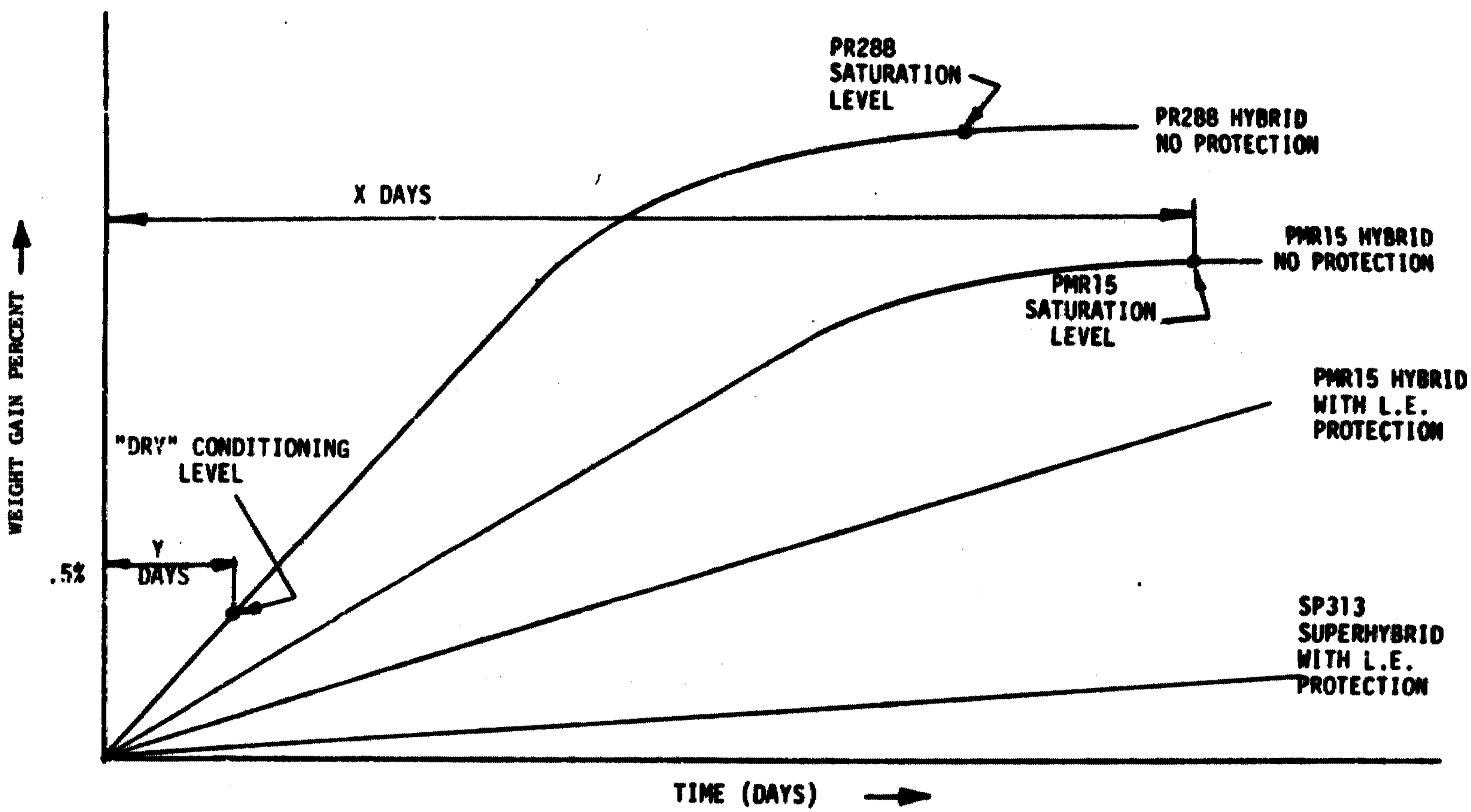


Figure 60. Conditioning Parameters for Tasks III and IV Specimens.

The PMR/T300/S "wet" calibration specimen with no leading edge protection (S/N PMRF-2) indicated full saturation (1.18 percent) after 41 days humidity conditioning as shown in Figure 61. The comparative PR288/AS/S "dry" calibration specimen had absorbed 2.18 percent moisture in the same time period. The two selected Task III test specimens, with the leading edge protection system, one hybrid S/N PMRF-27) and one superhybrid (S/N SPIII-5) together with a basic PR288/AS/S specimen (S/N PRIII-3) with the leading edge protection applied were monitored under the same humidity conditions (Ref: Figure 62).

The reduced moisture absorption caused by the fifty percent of the hybrid composite surface area being clad with the nickel plate and the superhybrid titanium foil cladding of the airfoil can be noted in Figure 62 compared to Figure 61. The slight weight gain of moisture in the superhybrid design was created by moisture ingress into the exposed composite core/adhesive joints at the cut end of the specimen and the joint line between the outer foil layers at the trailing edge.

The Task III specimen moisture conditioned weights and preimpact and postimpact torsional stiffness measurements are shown in Table XCV.

5.5 TORSIONAL STIFFNESS CALIBRATION

Clamps were fabricated to adapt the Task III specimens to the torsional stiffness apparatus used in Task II (Ref: Paragraph 4.5). Two nominally dry calibration specimens, one hybrid design PRIII-3 (PR288/AS/S Material) and one superhybrid specimen SPIII-4, were subjected to torque loads required to twist the specimen through 0.5, 1.0, 1.5 and 2.0 degree angles. The results of the equipment/specimen calibration trials are graphically shown in Figure 63. An angular displacement of 2 degrees was selected for measurement of the torsional stiffness of the specimens before and after impact as a means of qualifying impact damage. Tables XCI, Hybrid Specimens, XC11, Superhybrid Specimens tabulate the load required to twist each specimen through the 2 degrees angle in the pre-impact and post-impact conditions.

5.6 BALLISTIC IMPACT TESTING

The purpose of the impact testing was to evaluate the effects of temperature and moisture on the ballistic impact resistance of the two different material/construction design specimens. Multiple impacts were conducted on each specimen to determine the threshold level where initial local damage began to occur. A total of 86 impact shots were conducted on the 20 Task III specimens.

5.6.1 Equipment Calibration

A spare hybrid composite specimen was supplied to the University of Dayton for the purposes of calibrating the equipment for the 219 K (-65° F) and 394 K (250° F) temperature conditions.

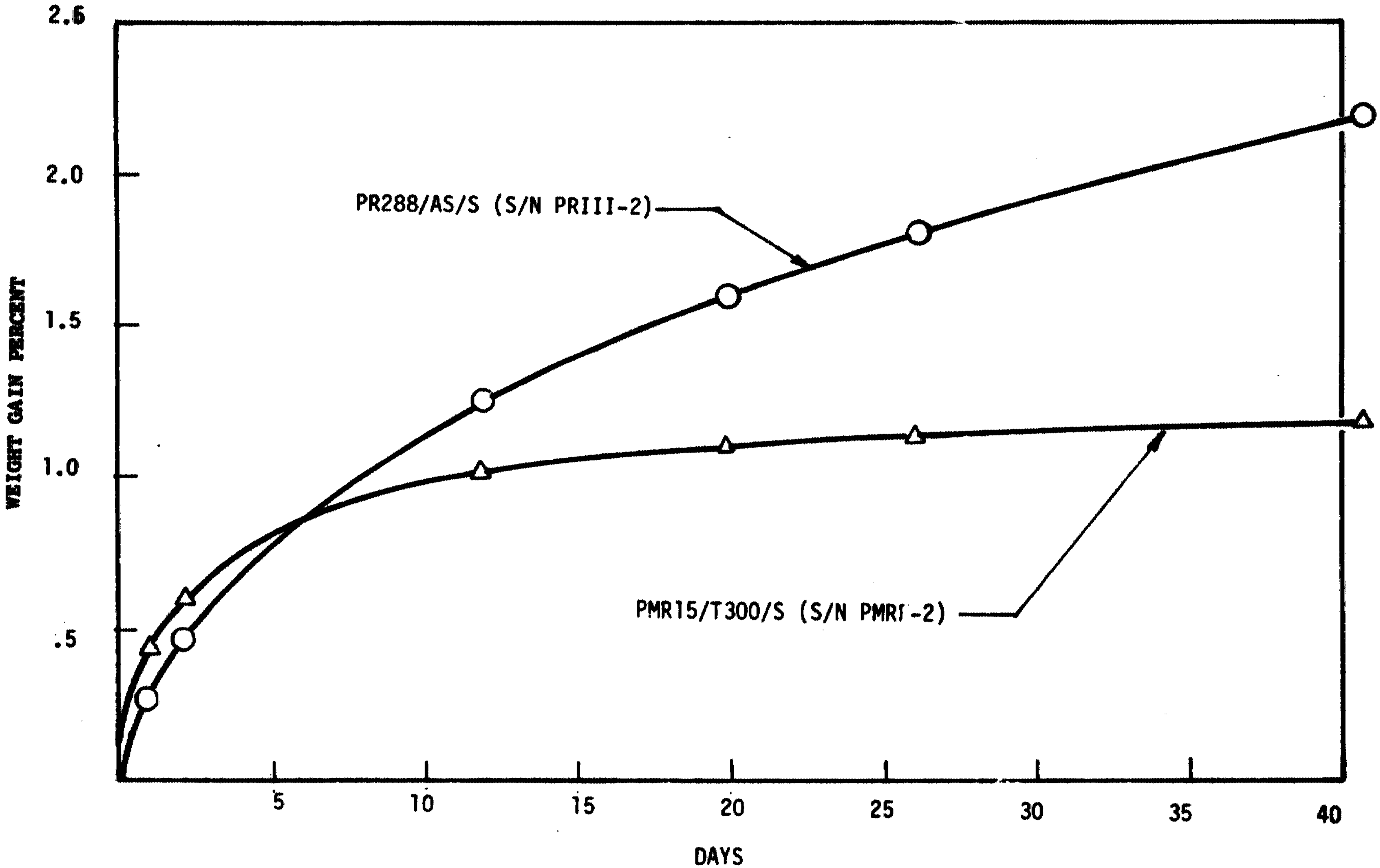


Figure 61. Task III Moisture Calibration Specimens Moisture Weight Gain Percentage Unprotected Specimens.

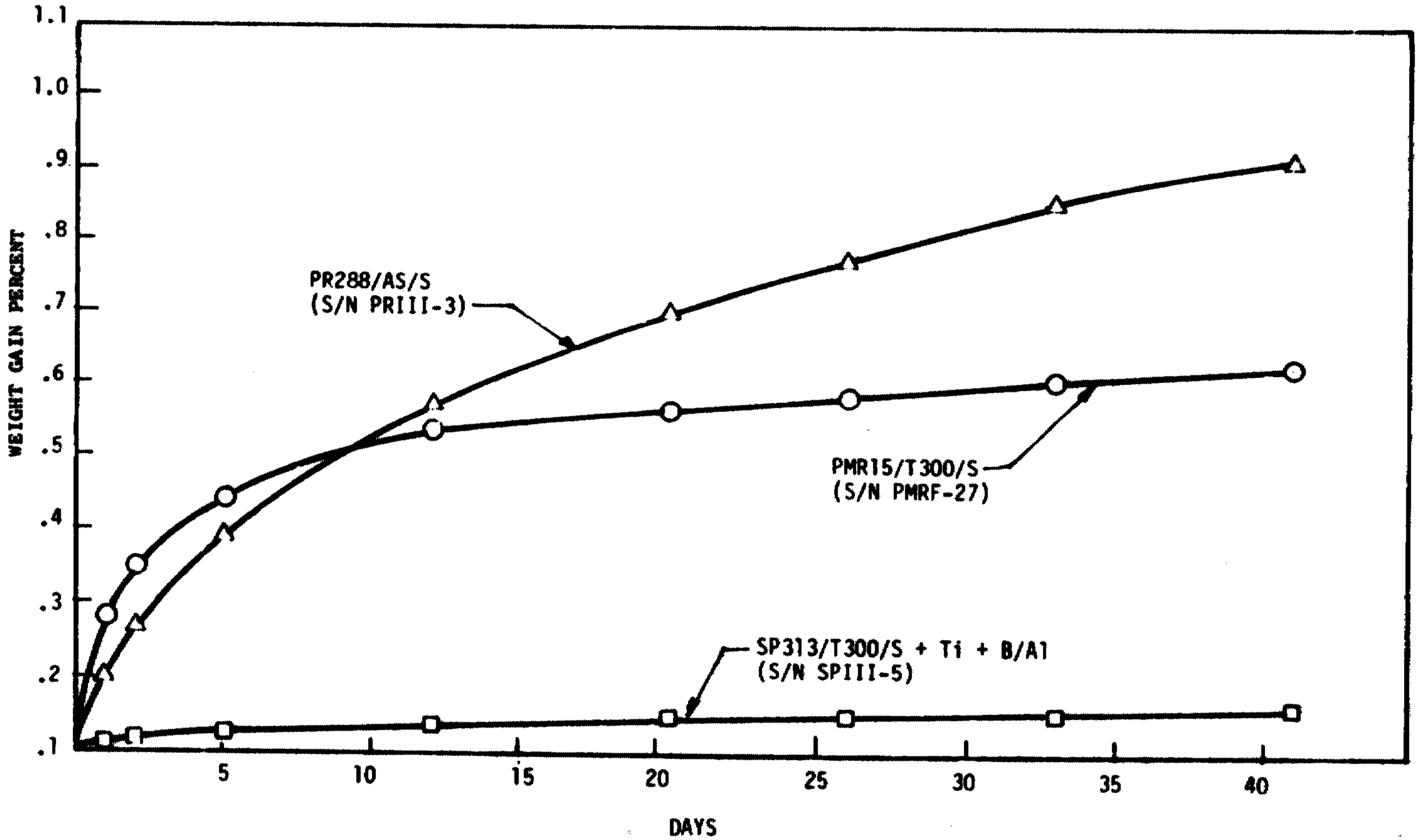


Figure 62. Task III Moisture Calibration SpecimensMoisture Weight Gain Percentage Specimens with Leading Edge Protection.

Table XCV. Task III Specimen Moisture Conditioned Weights and Torsional Stiffness Measurements (Report No. TI-3557).

Specimen No.	Envir. Condition	Impact Test Temperature	Preconditioned Fully Dry Weight (gms)	Moisture Conditioned Weight (gms)	Moisture Weight Percent	Torsional Stiffness Applied Load (gms) @ 2 degree TWIST		
						Preimpact	Post Impact	Percentage
SPIII-1	Dry	219 K (-65° F)	725.013	725.088	0.01	5884.4	5561.6	- 5.5
SPIII-7	Dry	219 K (-65° F)	719.123	719.258	0.02	6655.7	5107.3	-23.3
PMRF-13	Dry	219 K (-65° F)	609.708	611.388	0.28	4337.3	3621.3	-16.5
PMRF-20	Dry	219 K (-65° F)	603.228	604.873	0.27	3471.4	3455.5	- 0.5
SPIII-2	Dry	294 K (70° F)	706.318	706.453	0.02	5778.9	4316.1	-25.3
SPIII-9	Dry	294 K (70° F)	763.368	763.468	0.01	6850.0	7031.5	+ 2.6
PMRF-15	Dry	294 K (70° F)	661.228	612.998	0.29	4308.8	3314.3	-23.1
PMRF-21	Dry	294 K (70° F)	604.838	606.523	0.28	3413.8	3530.4	+ 3.4
SPIII-5	Wet	294 K (70° F)	698.043	698.648	0.09	6574.3	5206.0	-20.8
SPIII-8	Wet	294 K (70° F)	684.357	685.143	0.11	5153.7	4080.2	-20.8
PMRF-16*	Wet	294 K (70° F)	579.084	582.878	0.66	4930.3	4067.6	-17.5
PMRF-17	Wet	294 K (70° F)	615.114	618.503	0.55	3928.7	4002.8	+ 1.9
SPIII-3	Dry	394 K (250° F)	671.198	671.338	0.02	5421.4	4693.6	-13.4
SPIII-10	Dry	394 K (250° F)	711.533	711.618	0.01	5841.9	5538.6	- 5.2
PMRF-19	Dry	394 K (250° F)	579.148	580.863	0.30	3208.1	2808.7	-12.4
PMRF-22	Dry	394 K (250° F)	584.113	585.783	0.29	3549.9	2814.0	-20.7
SPIII-11	Wet	394 K (250° F)	720.691	721.428	0.10	6754.0	5244.0	-22.4
SPIII-13	Wet	394 K (250° F)	730.138	730.868	0.10	6582.9	5778.0	-12.2
PMRF-26	Wet	394 K (250° F)	588.498	592.193	0.63	2788.7	3428.8	- 9.5
PMRF-27	Wet	394 K (250° F)	600.776	604.343	0.59	3720.5	2652.1	-28.7

* Specimen Length 38.1 cm (15 in.) long

Note:
1) Pre-Condition: 24 hours at 394 K (250° F)
2) Dry-Condition: 2 Days @ 355 K (180° F)/97% RH
3) Wet Condition: 355 K (180° F)/97% RH till saturation

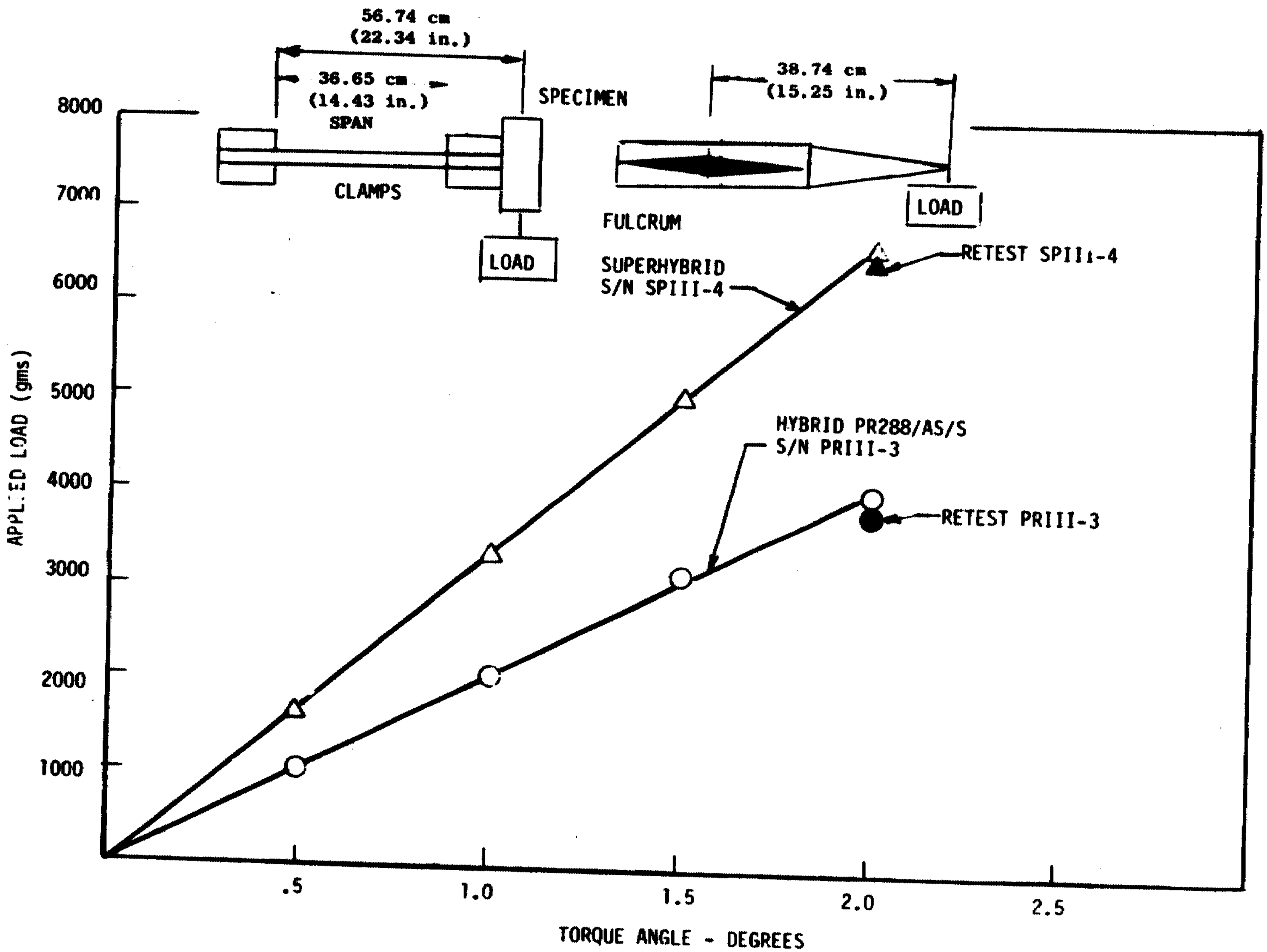


Figure 63. Task III Specimen Torsional Test Calibration.

A hole was drilled within the specimen tip such that a thermocouple could be positioned internally within the specimen. This internal temperature was utilized as the reference temperature for the hot and cold temperature requirements. Figure 64 shows the depth and location of the hole at the specimen tip and the location in the calibration tests.

The cold and hot specimen temperature requirements were achieved by enclosing the test specimens in an insulated enclosure (Figures 65 and 66) which was fabricated of 1.5 cm (0.625 in.) thick particle board. The temperature in the enclosure was maintained using liquid nitrogen for 219 K (-65° F) tests (Figure 65) and a resistance heater (blower) to achieve the 394 K (250° F) temperature (Figure 66). Calibration curves were generated for the desired temperature requirement. Figures 67 and 68 present temperature versus time plots for the 219 K (-65° F) and 394 K (250° F) temperatures, respectively for the hybrid composite specimen used as a calibration specimen. Notice that the temperatures were overshot in both temperature requirements. The insulated box was then removed and the test specimen to be impacted was permitted to either cool down or warm up depending on the temperature requirement. For the actual impacts, only the surface temperature at the root was monitored and the calibration curves were used to determine what the surface temperature had to be to have the internal temperature at the desired level. In the case for the 219 K (-65° F) shots, the skin temperature was 216 K (-70° F) when the internal temperature was at 219 K (-65° F). In the case for the 394 K (250° F) shots, the skin temperature cooled back to 366 K (200° F) when the internal temperature was at the desired 394 K (250° F) level. When the desired temperature levels were reached, the specimen was impacted with a full bite of the artificial bird.

5.6.2 Impact Tests

The tests were conducted in accordance with the specimen allocation and test matrix shown in Table XCIII. The 85 grams (3 ounce) microballoon gelatin "bird" was launched such that the whole "bird" (fullbite) would impact the specimen leading edge. In some cases, a small piece of the bird would be sliced by the leading edge which did not impact the specimen. In the case where slicing occurred, a catching system was positioned directly behind the specimens to capture the portion of the bird not impacting the specimen such that an accurate impact mass impacting the specimens could be calculated. The specmens were impacted at a starting velocity of about 152.5 to 183 m/sec (500 to 600 ft/sec) at an incidence angle of 25 degrees. After the first impact, the test velocities were then increased in increments of about 22.9 to 30.5 m/sec (75 to 100 ft/sec) until initial local composite damage was achieved. Damage was determined by ultrasonic hand scanning and visual inspection of each specimen after every impact.

A sketch was made of any damage resulting from the impact. Figures 69 through 72 show the resulting damage to the specimens tested at 219 K (-65° F) 'dry', Figures 73 through 77, 294 K (70° F) 'dry', Figures 78 through 82, 294 K (70° F) 'wet', Figures 83 through 87, 394 K (250° F) 'dry' and Figures 88

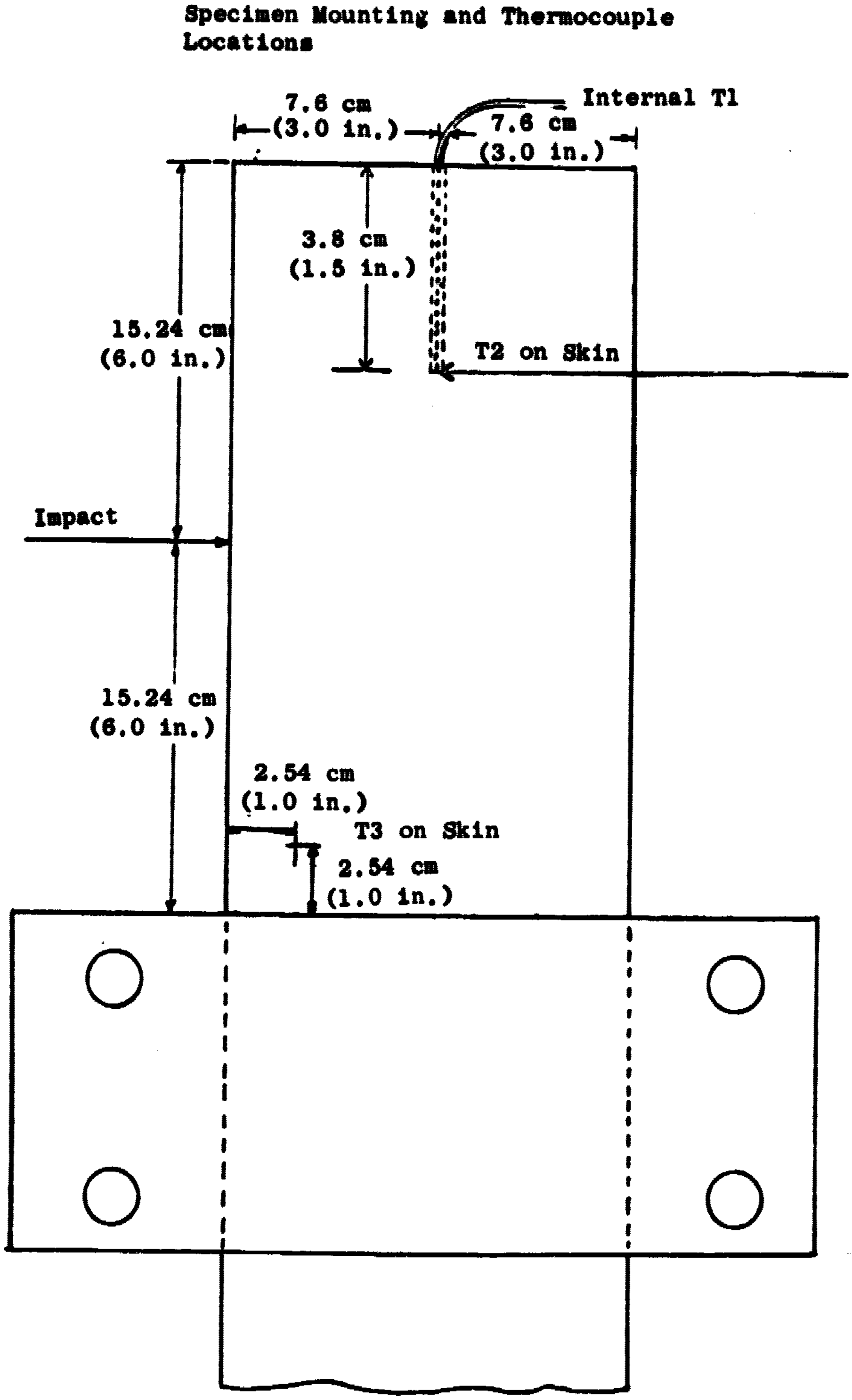


Figure 64. Specimen Mounting and Calibration Thermocouple Locations.

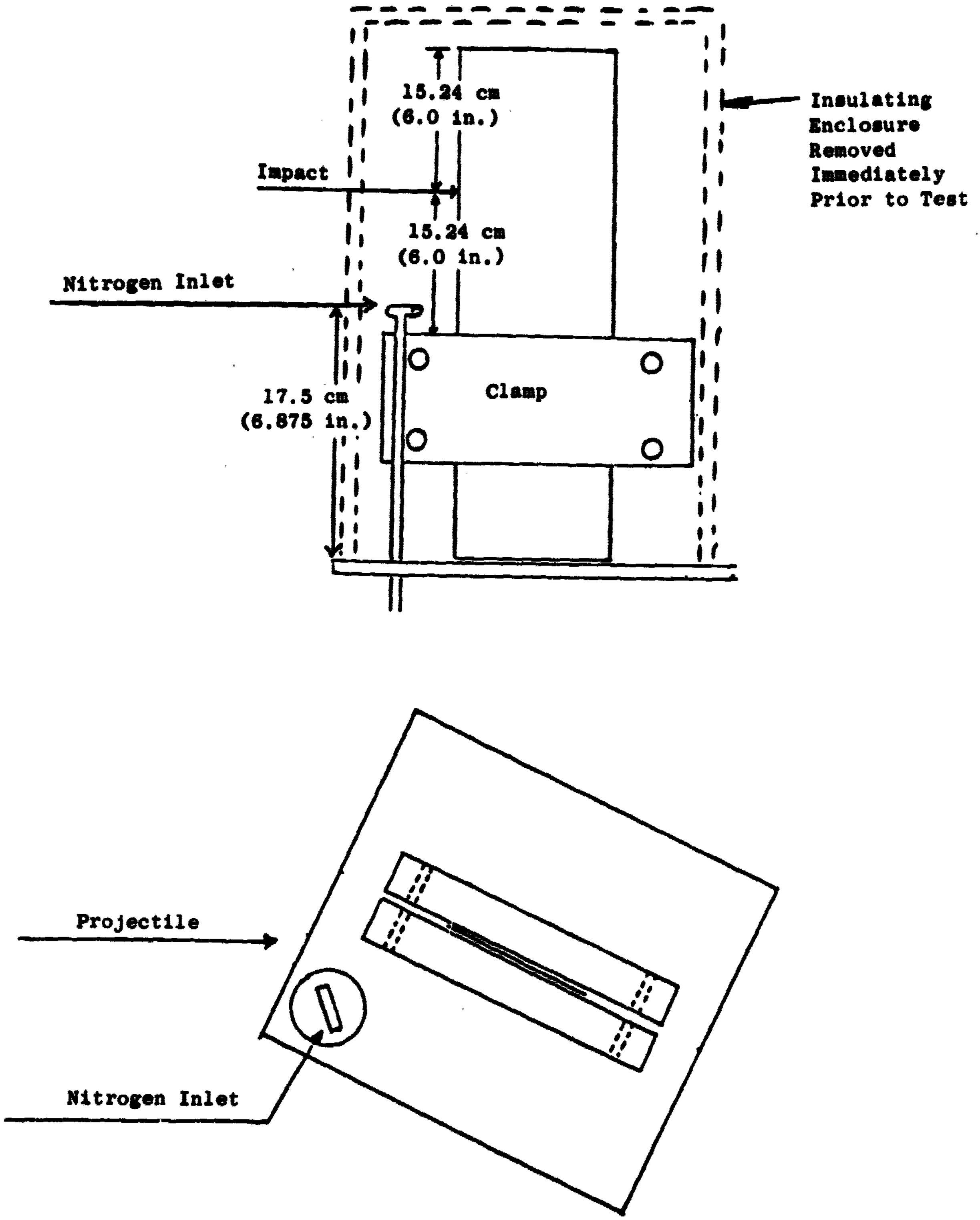


Figure 65. Sketch of Cooling System Employed.

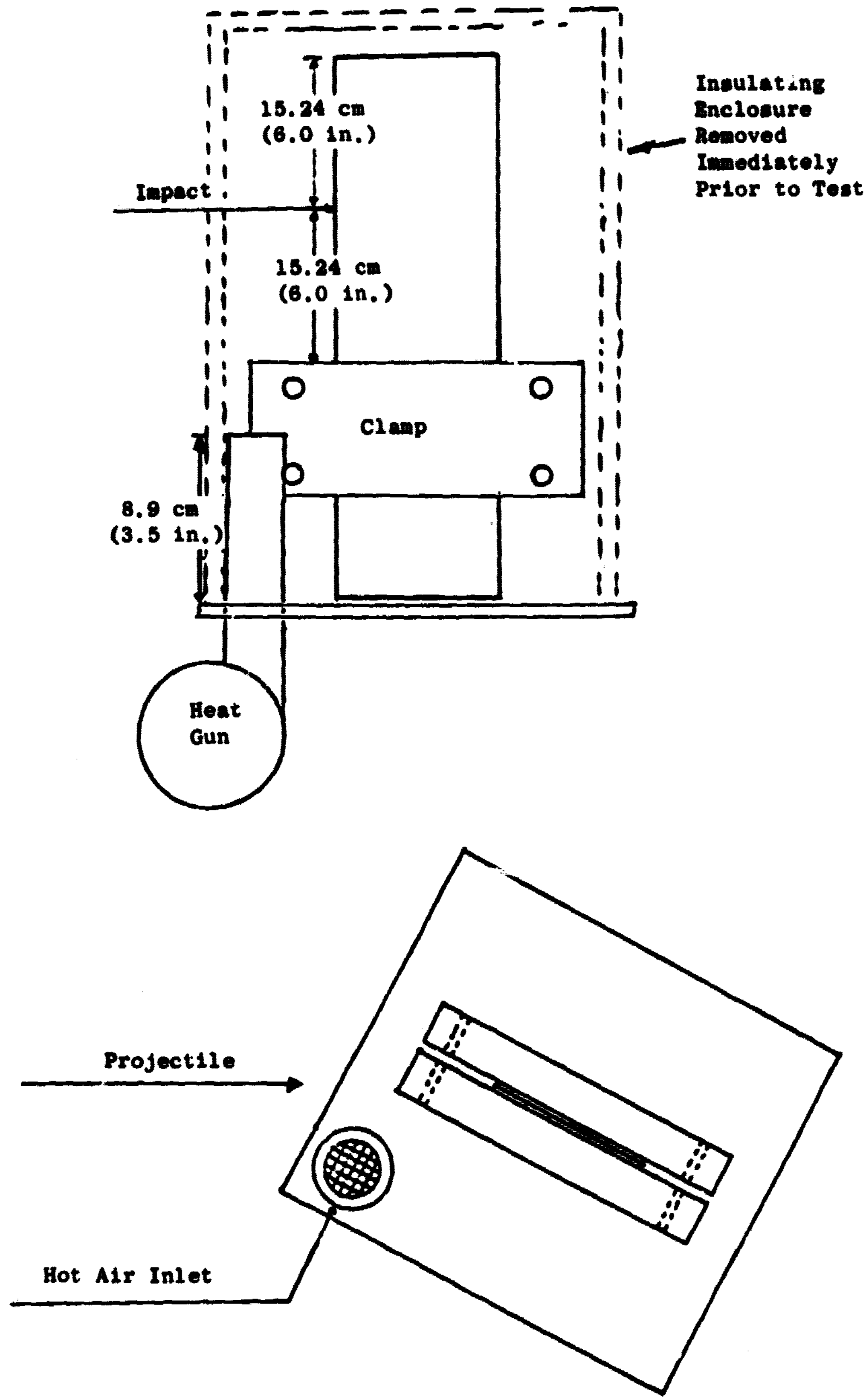


Figure 66. Sketch of Heating System Employed.

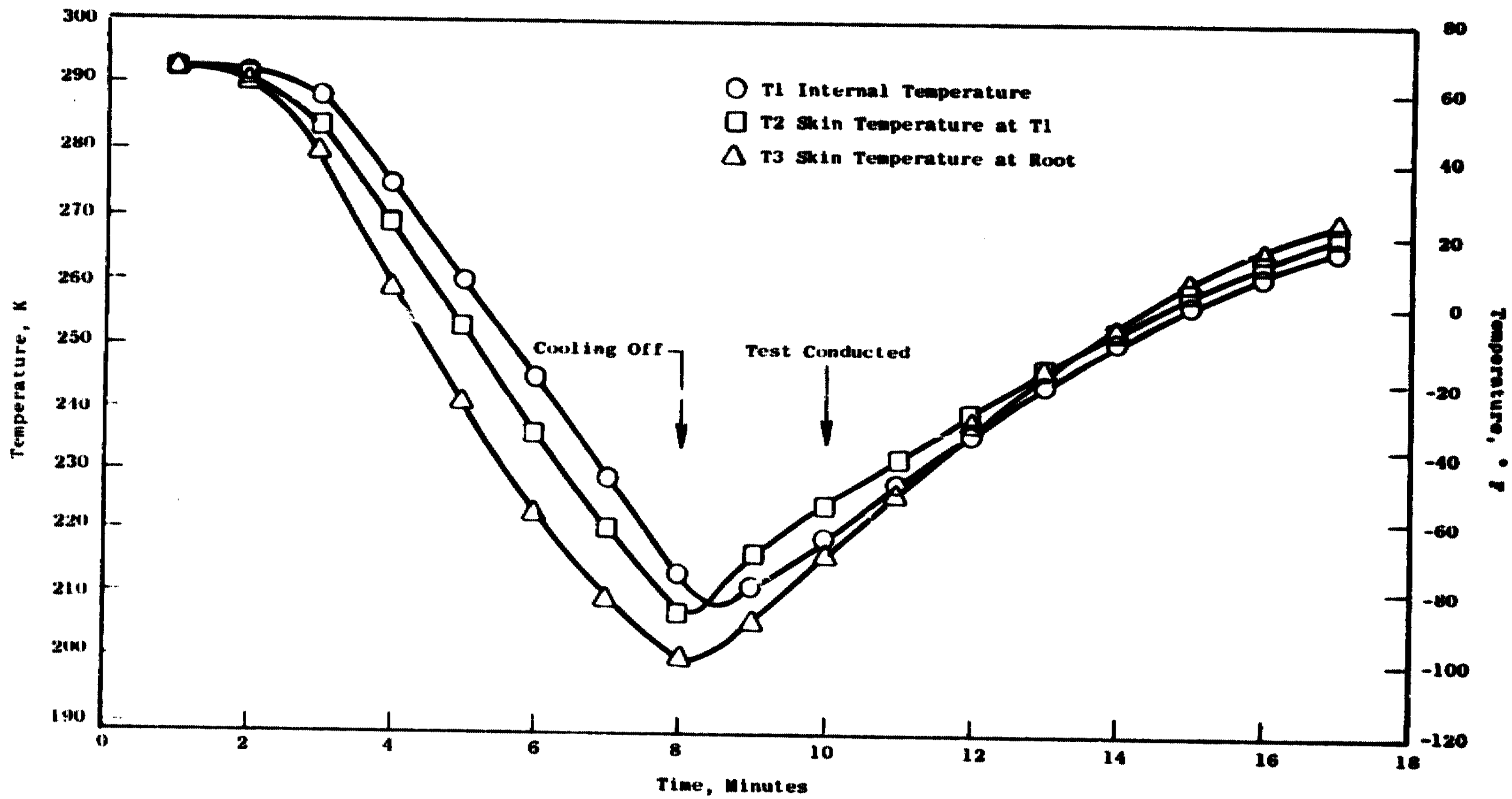


Figure 67. Calibration Curve for 219 K (-65° F) Impacts.

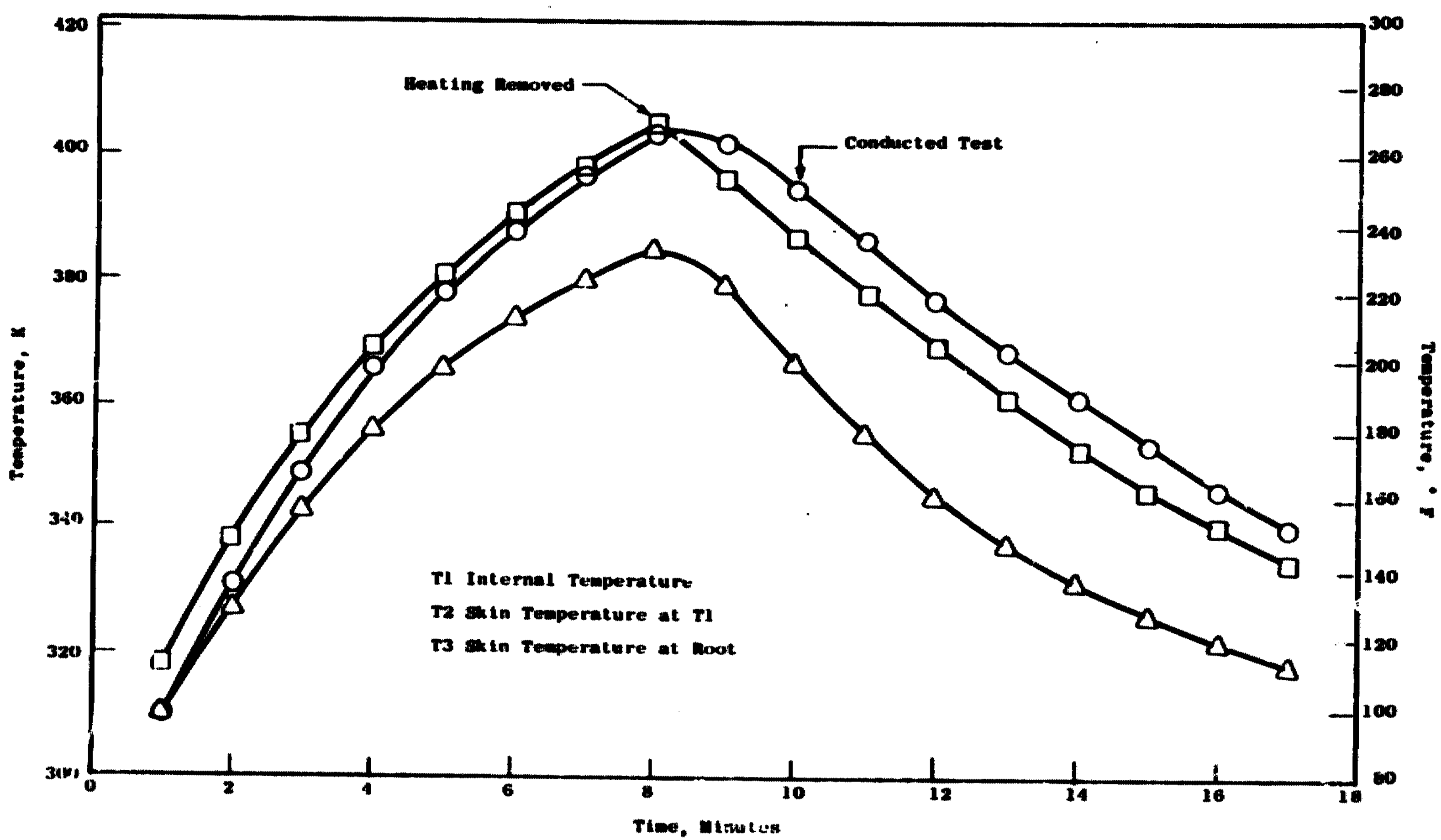


Figure 68. Calibration Curve for 394 K (250° F) Impacts.

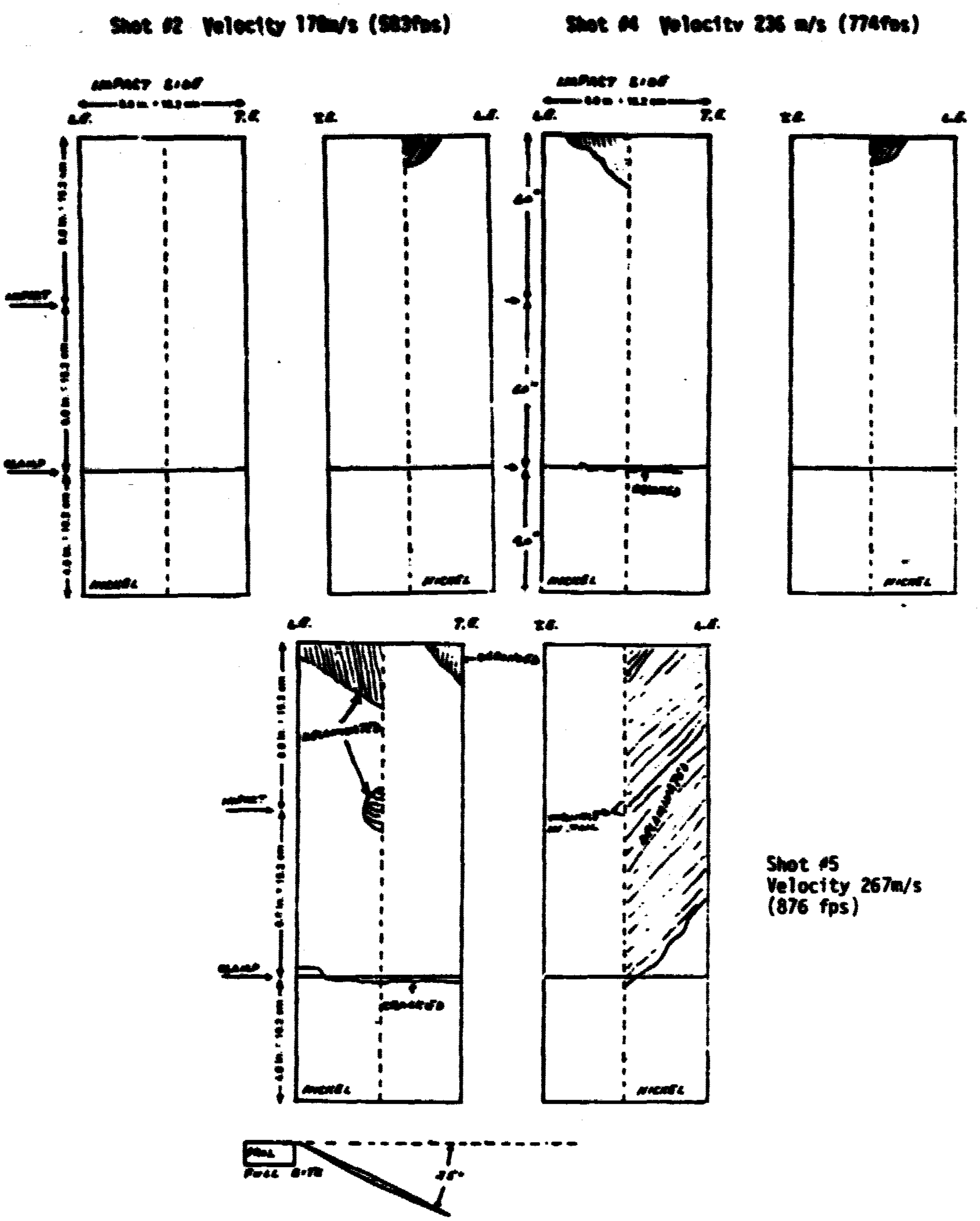
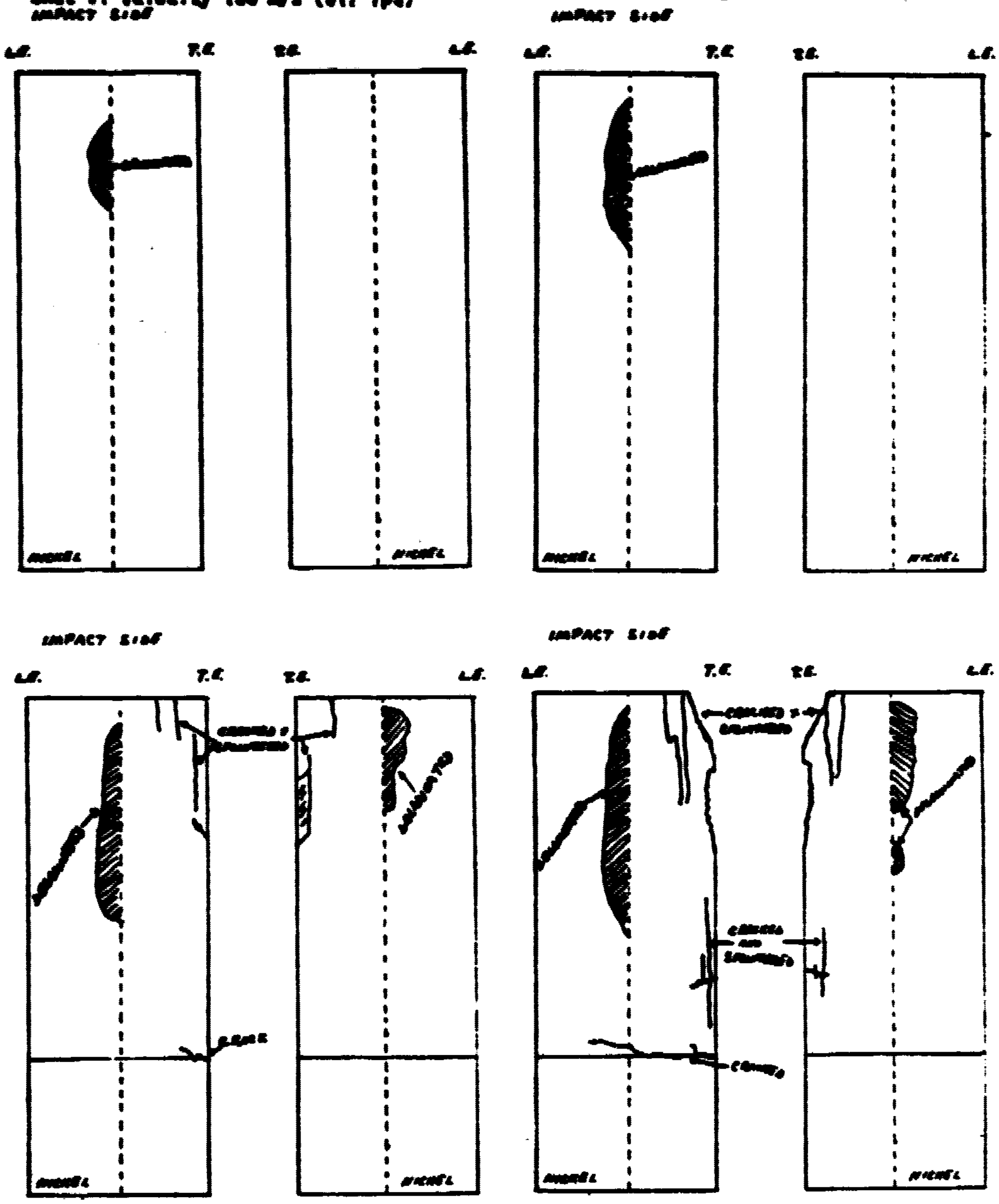


Figure 69. Superhybrid Specimen (SPIII-1) Impact Damage Tested at 219 K (-65° F) Dry.

Shot #1 Velocity 158 m/s (517 fps)

Shot #2 Velocity 186 m/s (610 fps)



Shot #3 Velocity 221 m/s (725 fps)

Shot #4 Velocity 243 m/s (796 fps)

Figure 71. Hybrid Specimen (PMRF-13) Impact Damage Tested at 219 K (-65° F) Dry.

Shot #3 Velocity 210 m/s (688 fps) Shot #4 Velocity 247 m/s (810 fps)

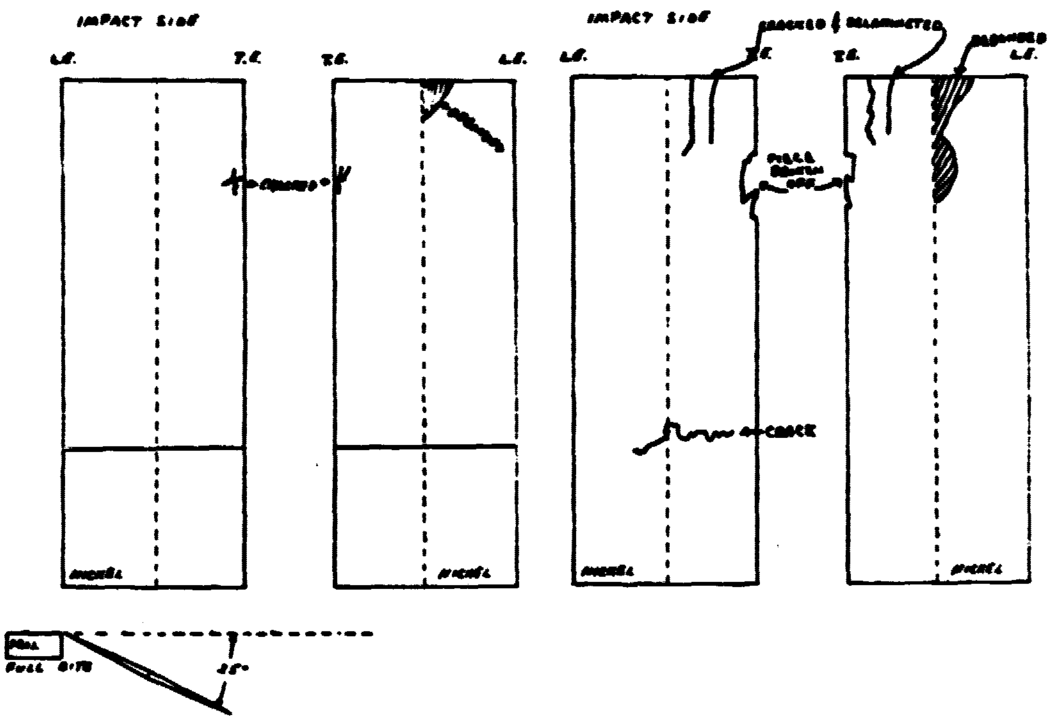
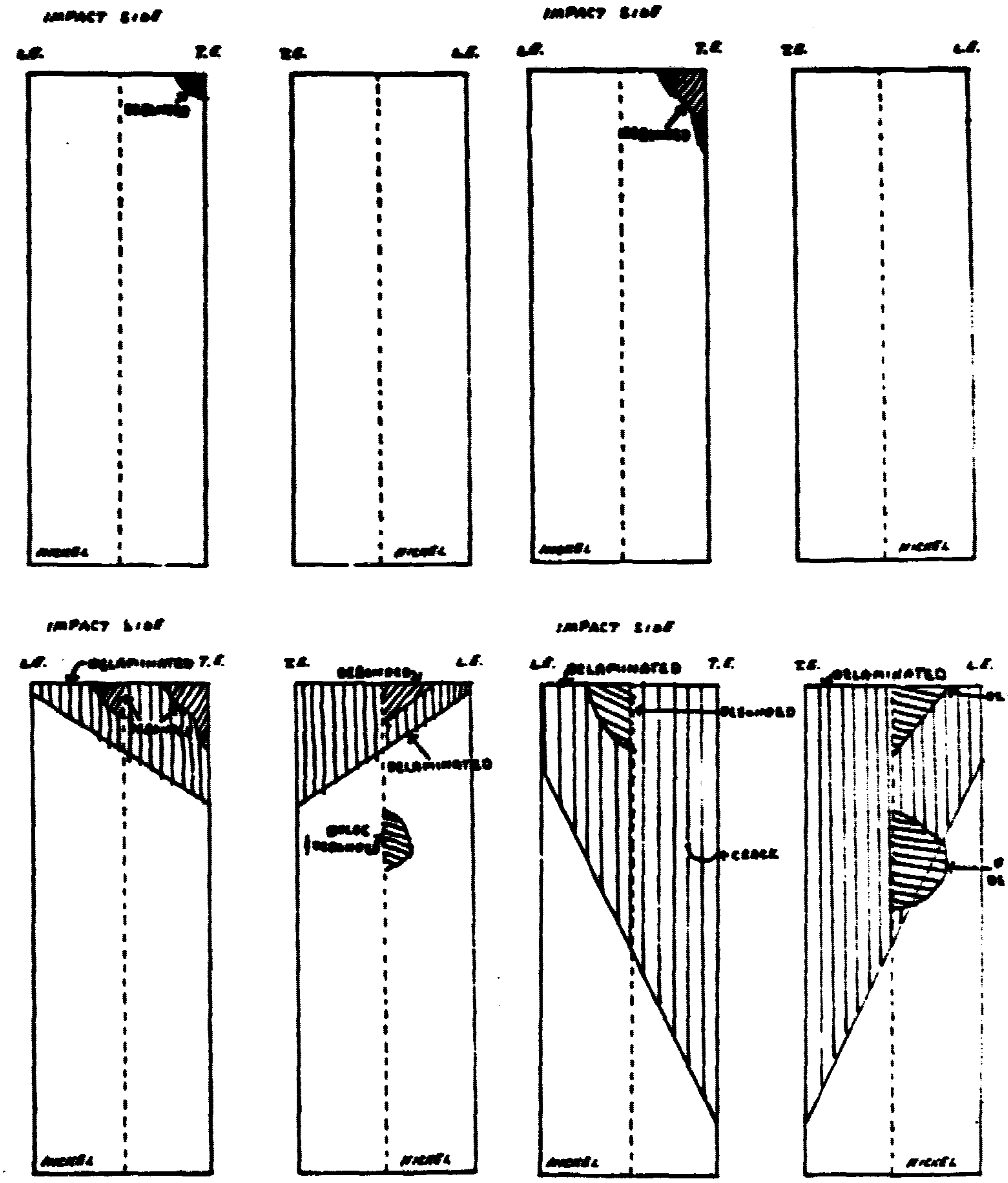


Figure 72. Hybrid Specimen (PMRF-20) Impact Damage Tested at 219 K (-65° F) Dry.

Shot #3 Velocity 217 m/s (712 fps) Shot #4 Velocity 245 m/s (803 fps)



Shot #5 Velocity 274 m/s (900 fps) Shot #6 Velocity 285 m/s (436 fps)

Figure 73. Superhybrid Specimen (SPIII-2) Impact Damage Tested at 294 K (70° F) Dry.

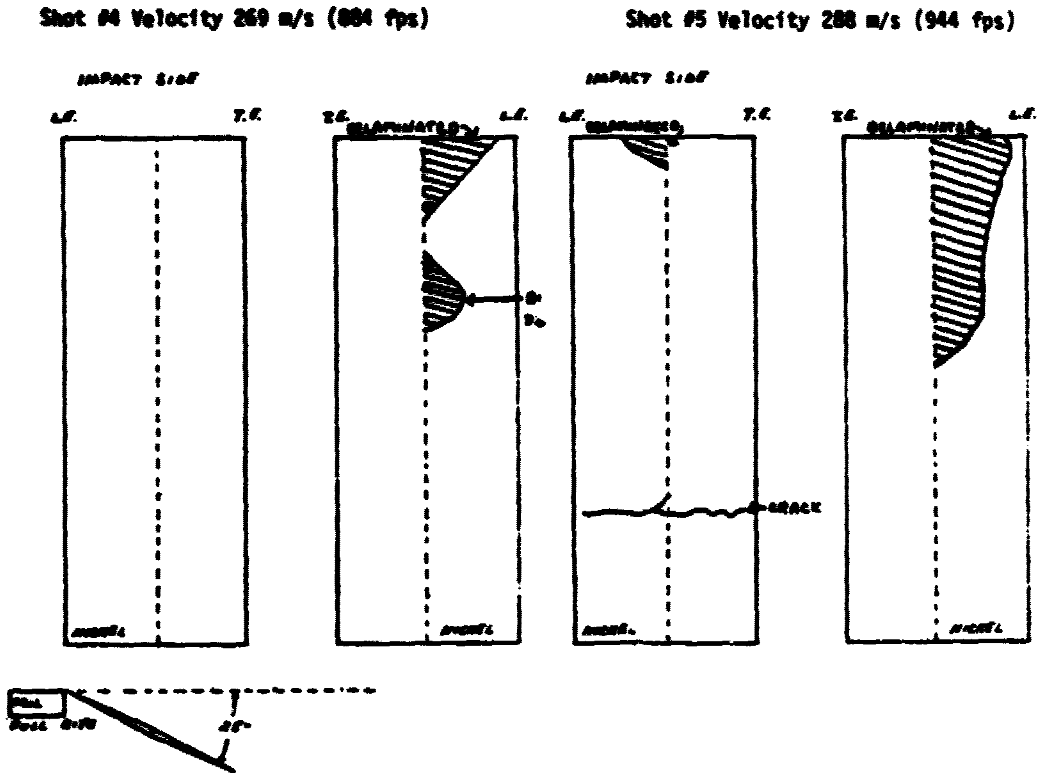


Figure 74. Superhybrid Specimen (SPIII-9) Impact Damage Tested at 294 K (70° F) Dry.

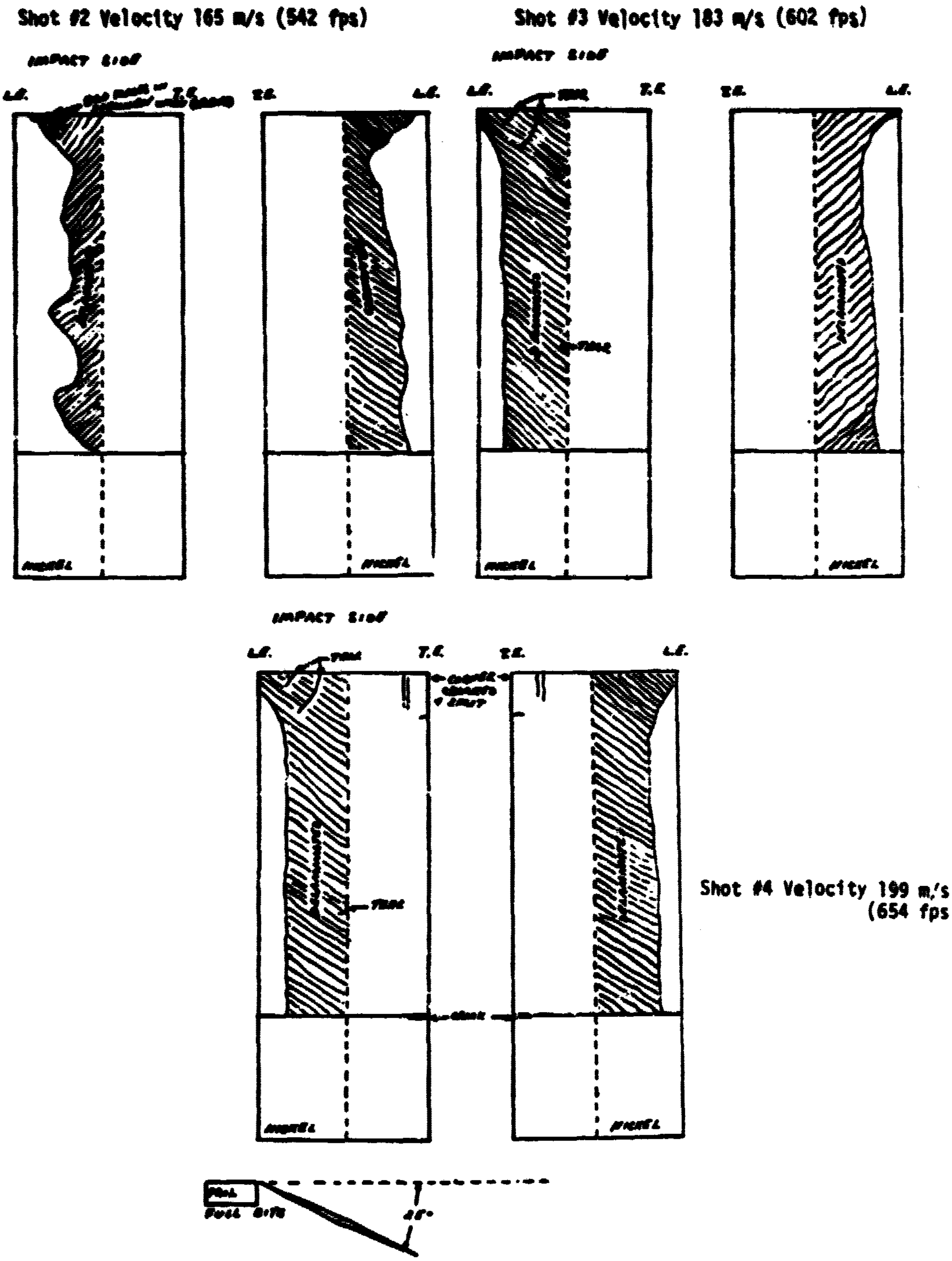


Figure 75. Hybrid Specimen (PMRF-15) Impact Damage Tested at 294 K (70° F) Dry.

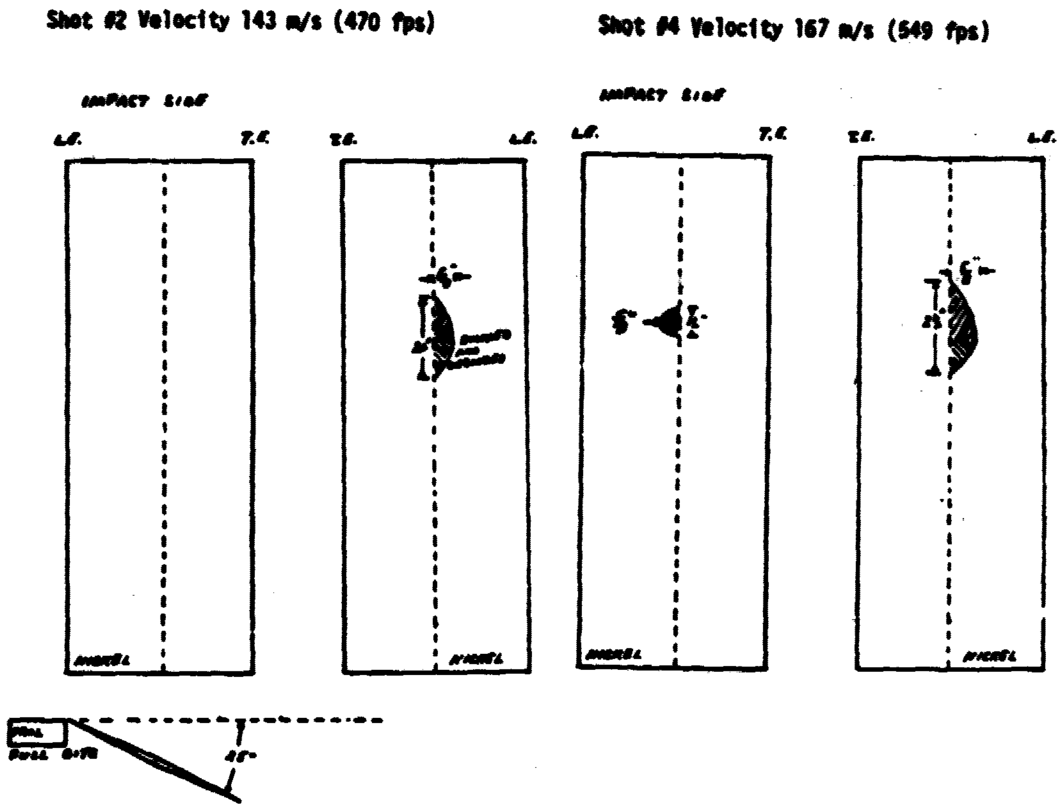


Figure 76. Hybrid Specimen (PMRF-21) Impact Damage Tested at 294 K (70° F) Dry.

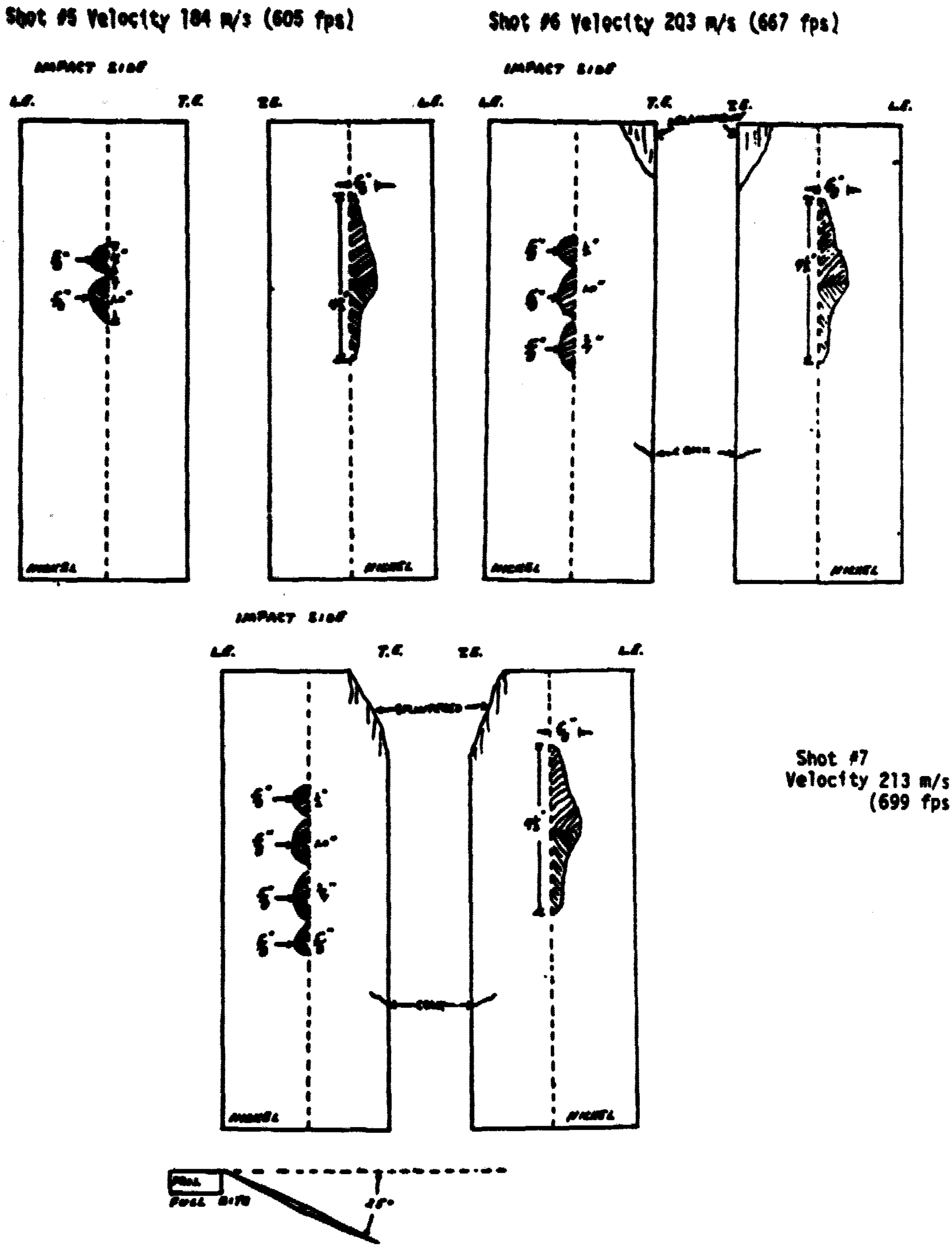


Figure 77. Hybrid Specimen (PMRF-21) Impact Damage Tested at 294 K (70° F) Dry.

Shot #1 Velocity 211 m/s (693 fps)

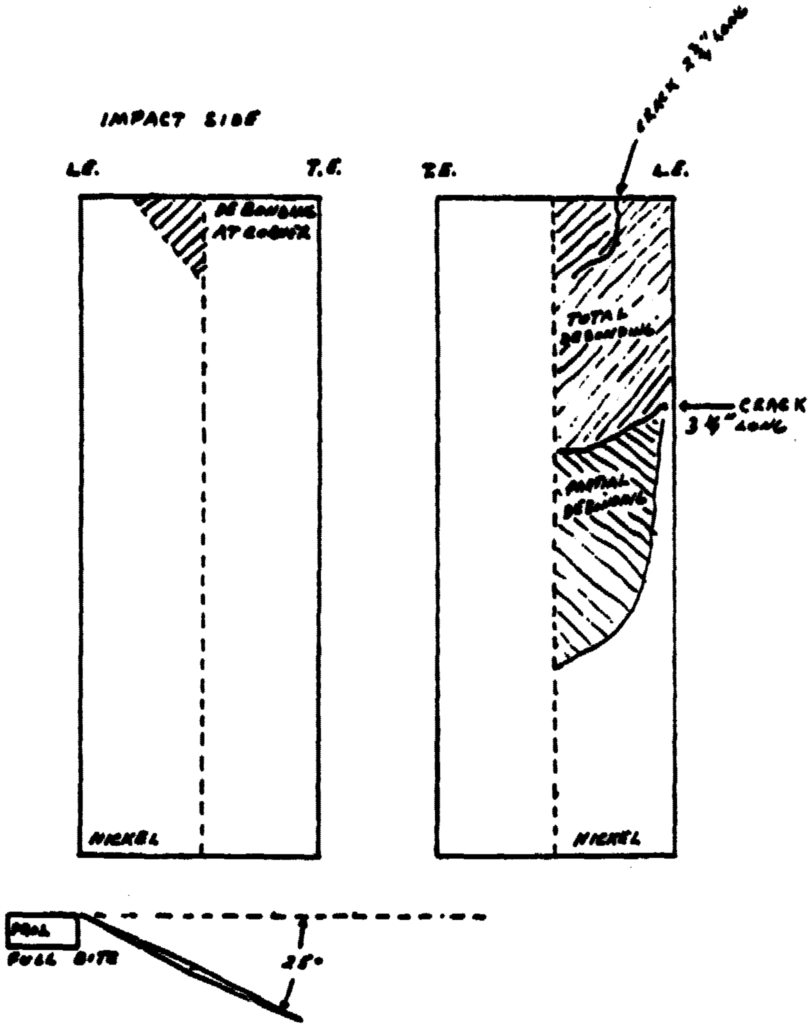


Figure 78. Superhybrid Specimen (SPIII-5) Impact Damage Tested at 294 K (70° F) Wet.

Shot #1 Velocity 121 m/s (398 fps)

Shot #2 Velocity 136 m/s (445 fps)

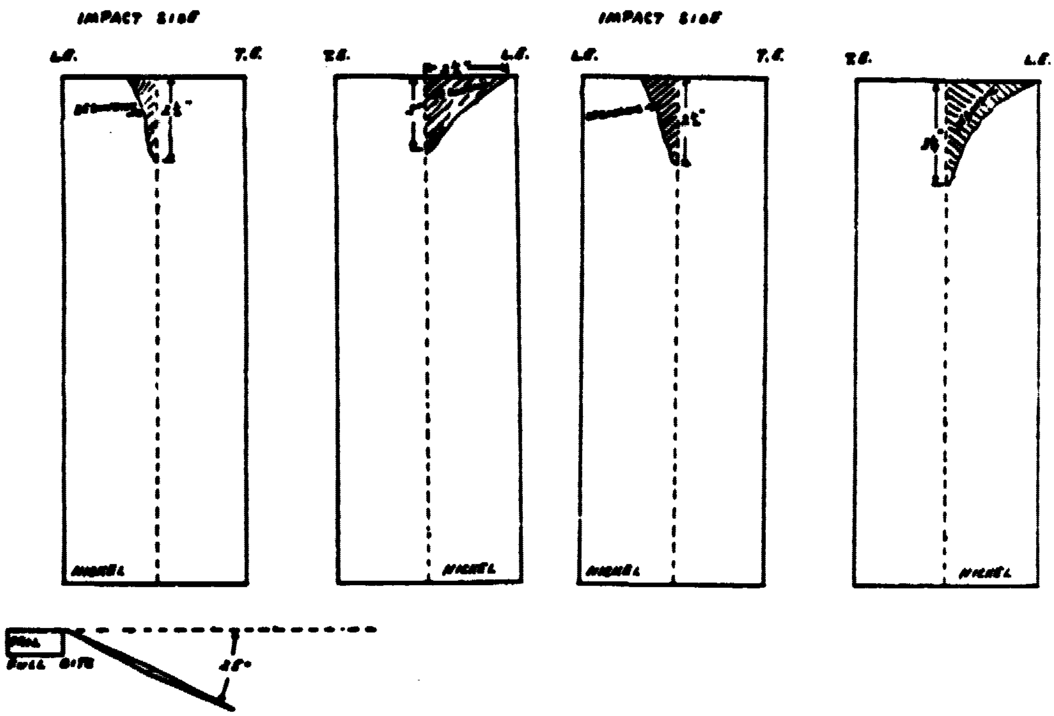
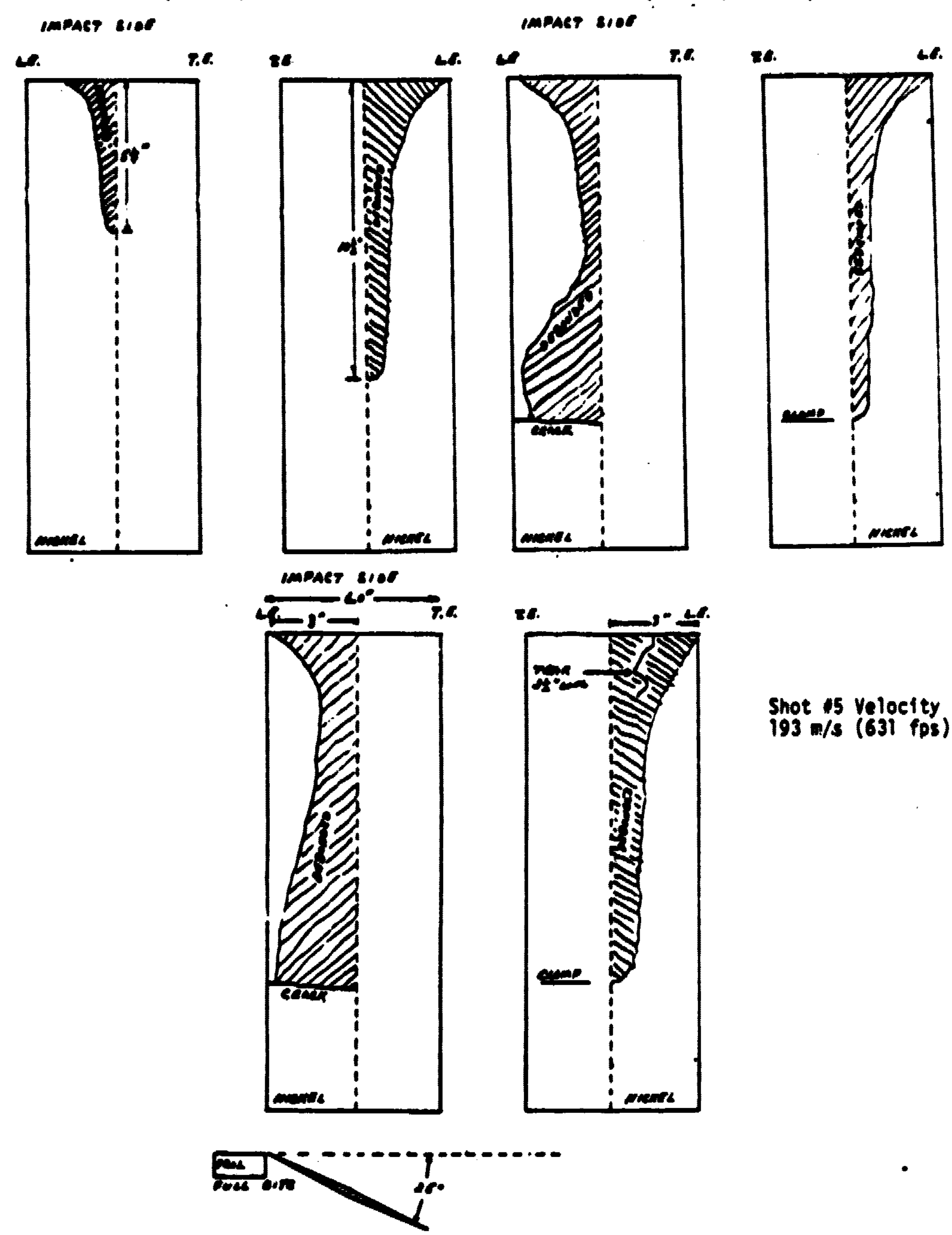


Figure 79. Superhybrid Specimen (SPIII-8) Impact Damage Tested at 294 K (70° F) Wet.

Shot #3 Velocity 165 m/s (541 fps) Shot #4 Velocity 164 m/s 553 fps)



Shot #5 Velocity 193 m/s (631 fps)

Figure 80. Superhybrid Specimen (SPIII-8) Impact Damage Tested at 294 K (70° F) Wet.

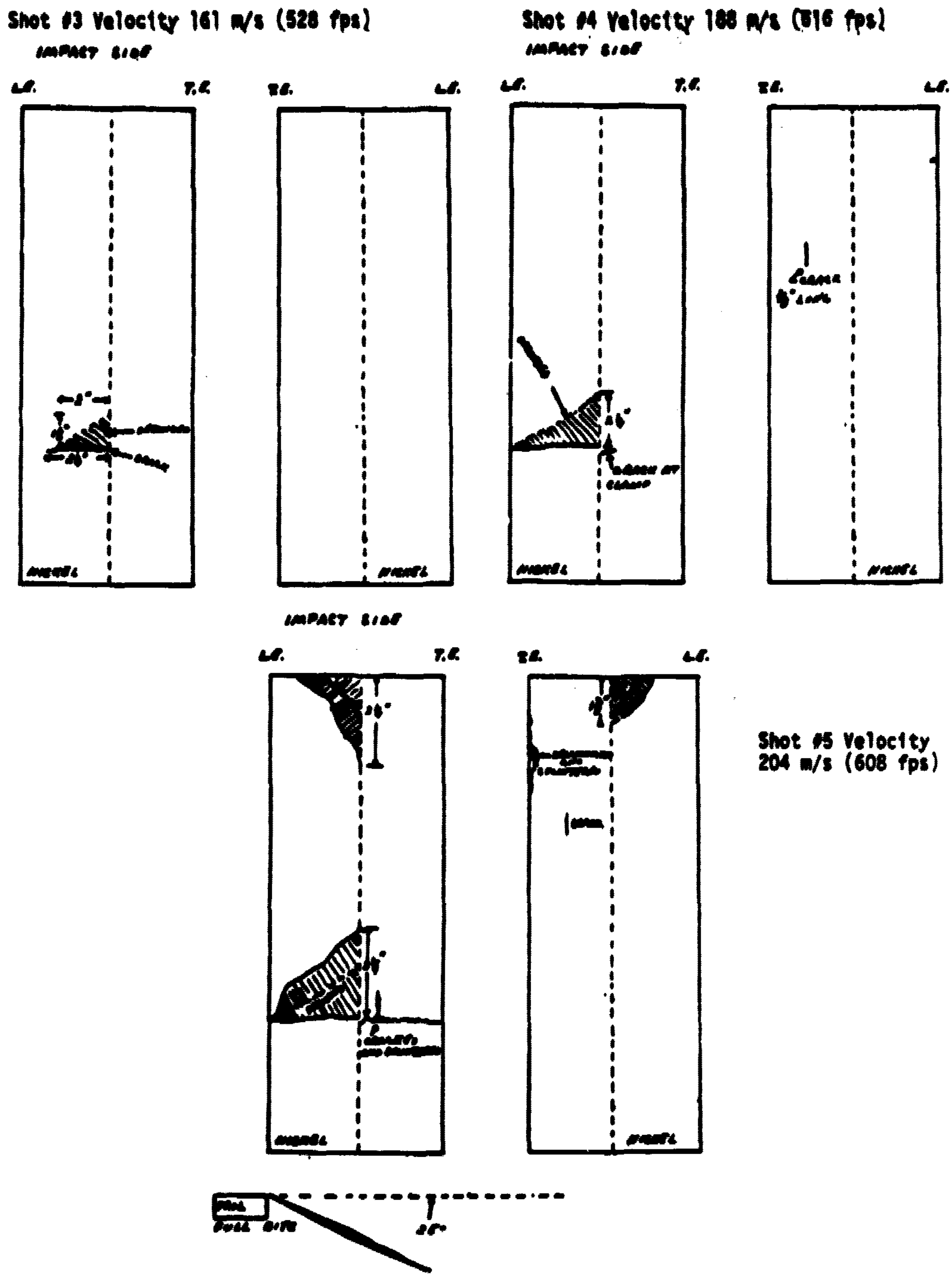


Figure 81. Hybrid Specimen (PMRF-16) Impact Damage Tested at 294 K (70° F) Wet.

Shot #2 Velocity 183 m/s (600 fps)

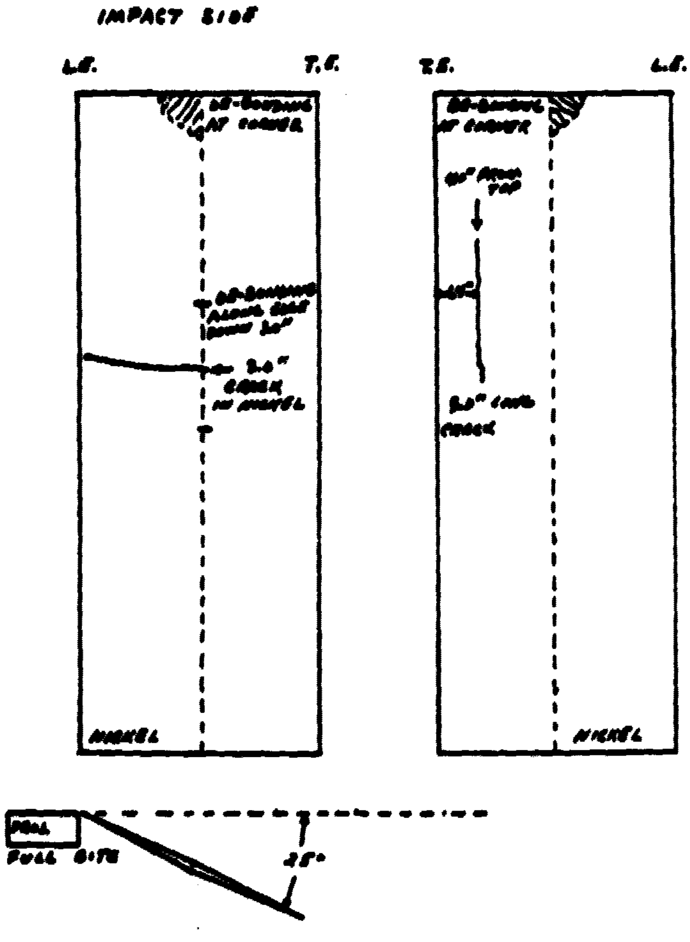


Figure 82. Hybrid Specimen (PMRF-17) Impact Damage Tested at 294 K (70° F) Wet.

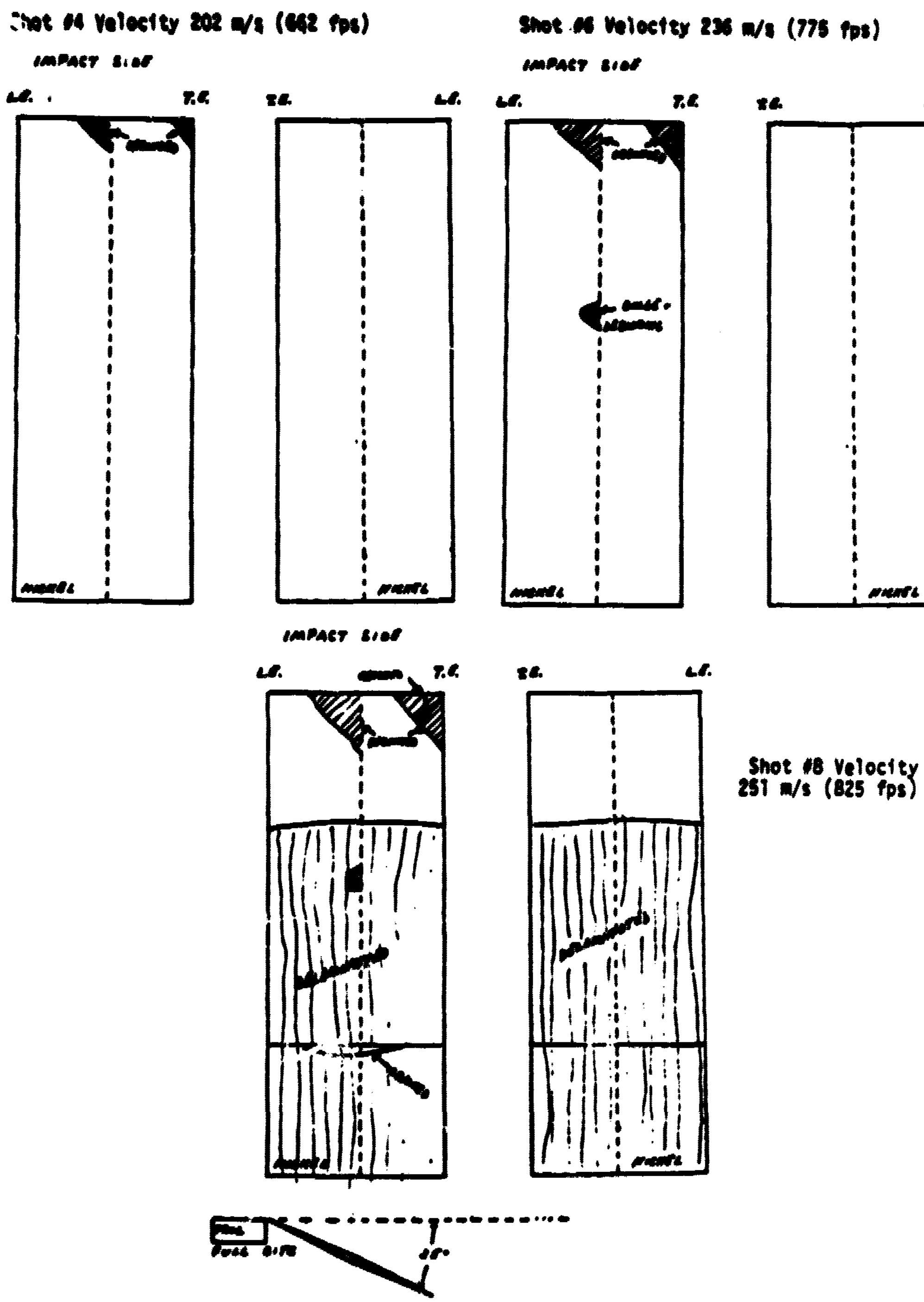


Figure 83. Superhybrid Specimen (SPIII-3) Impact Damage Tested at 394 K (250° F) Dry.

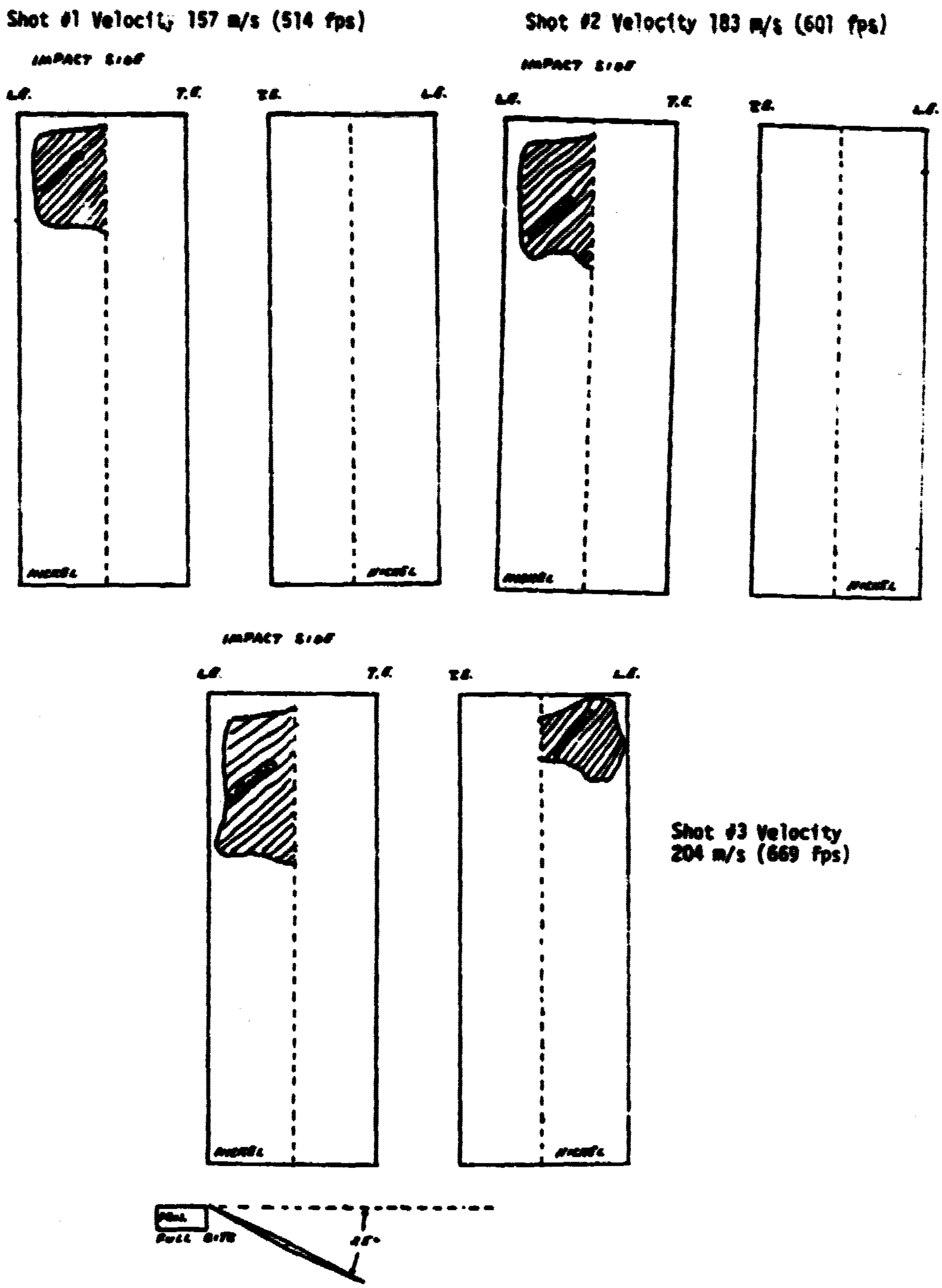


Figure 84. Superhybrid Specimen (SPIII-10) Impact Damage Tested at 394 K (250° F) Dry.

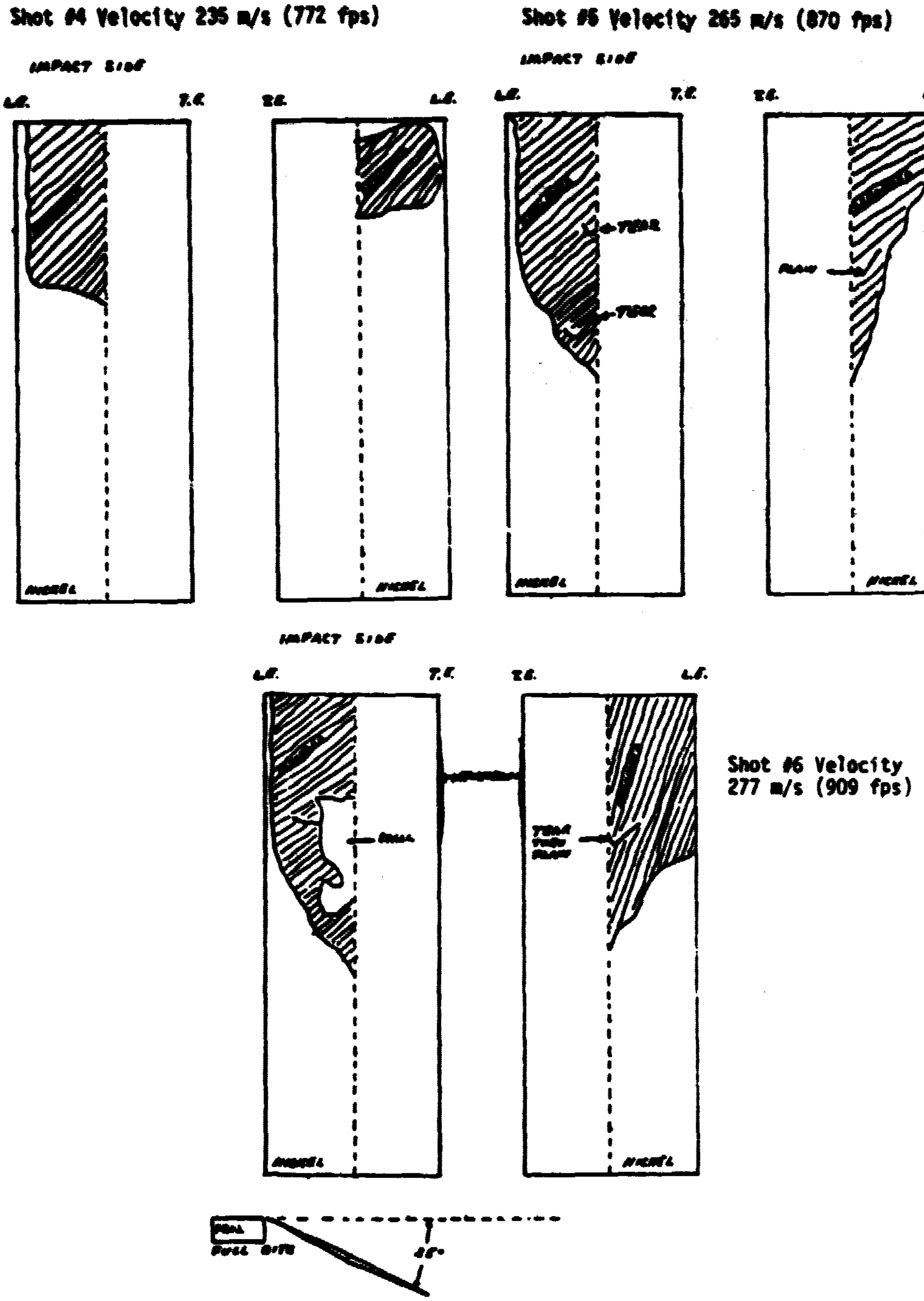


Figure 85. Superhybrid Specimen (SPIII-10) Impact Damage Tested at 394 K (250° F) Dry.

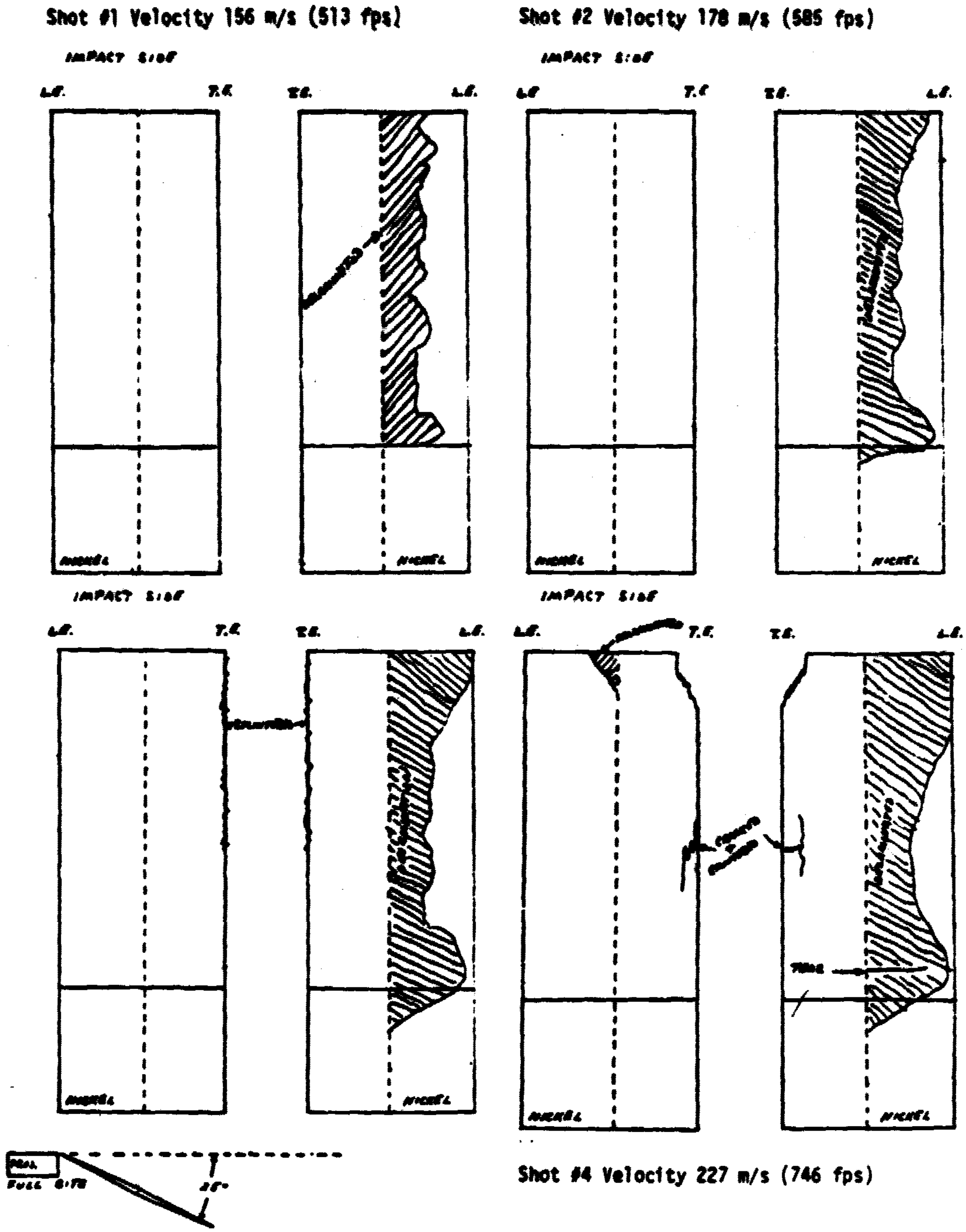


Figure 86. Hybrid Specimen (PMRF-19) Impact Damage Tested at 394 K (250° F) Dry.

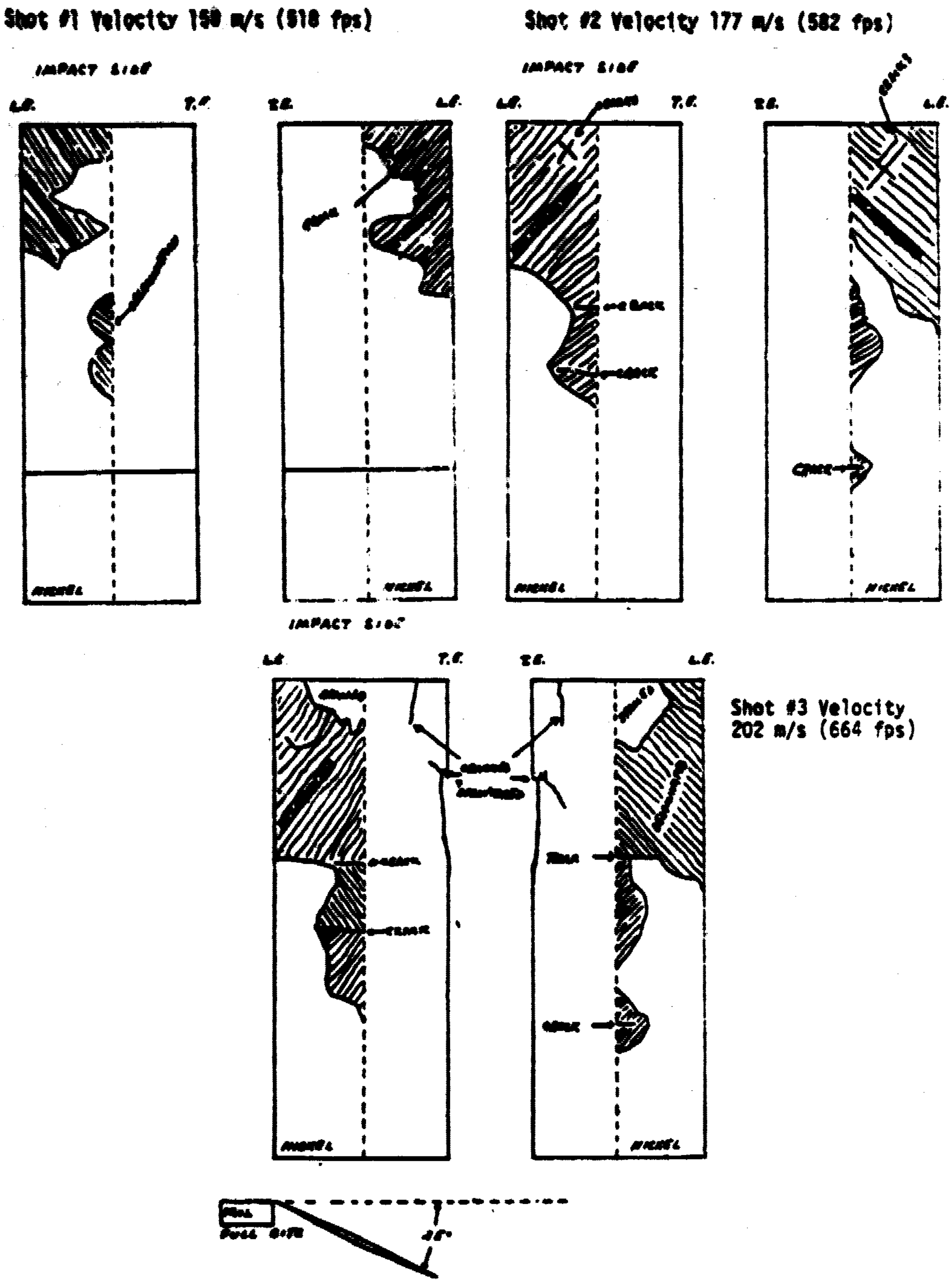


Figure 87. Hybrid Specimen (PMRF-22) Impact Damage Tested at 394 K (250° F) Dry.

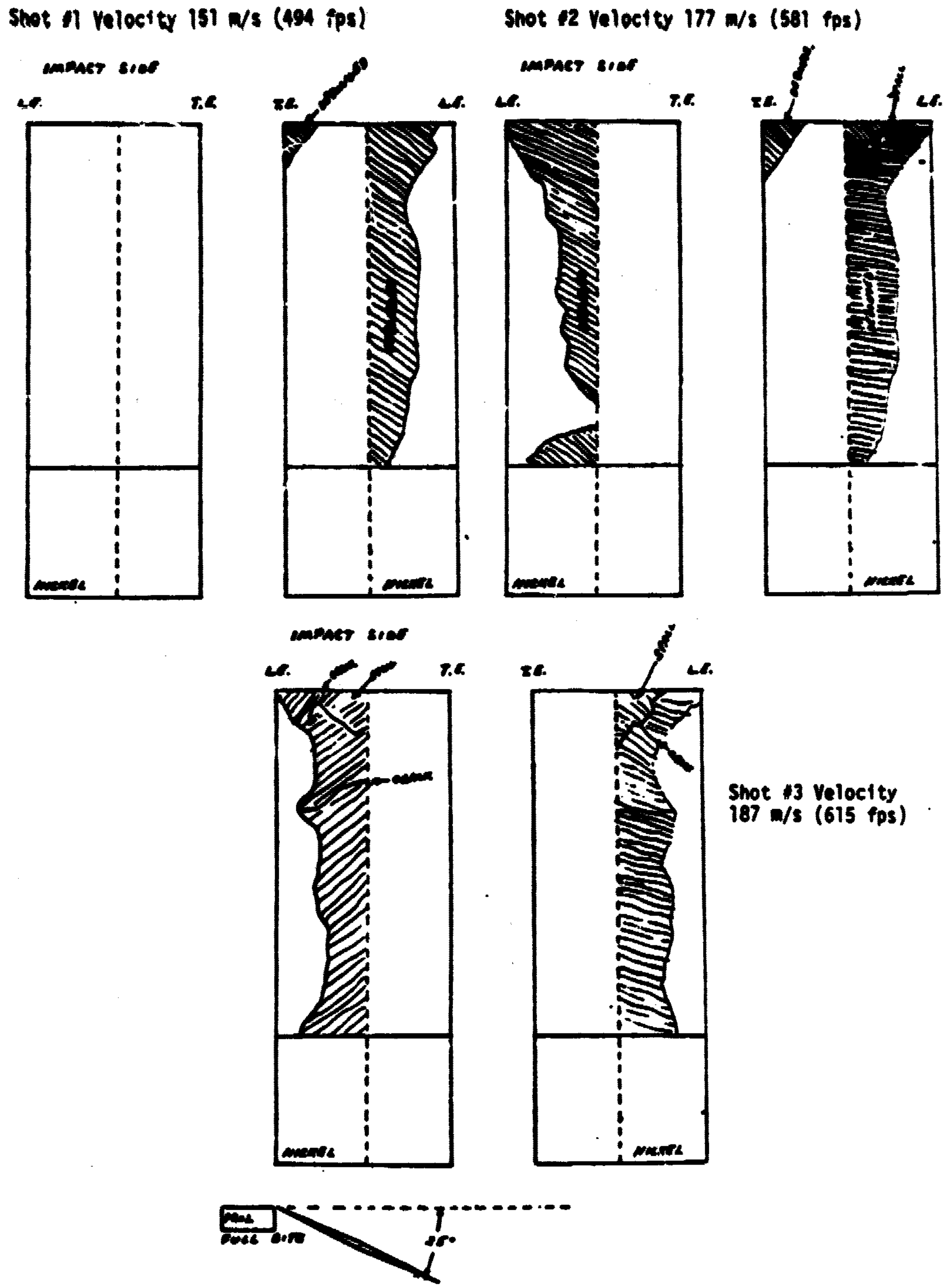


Figure 88. Superhybrid Specimen (SPIII-11) Impact Damage Tested at 394 K (250° F Wet.

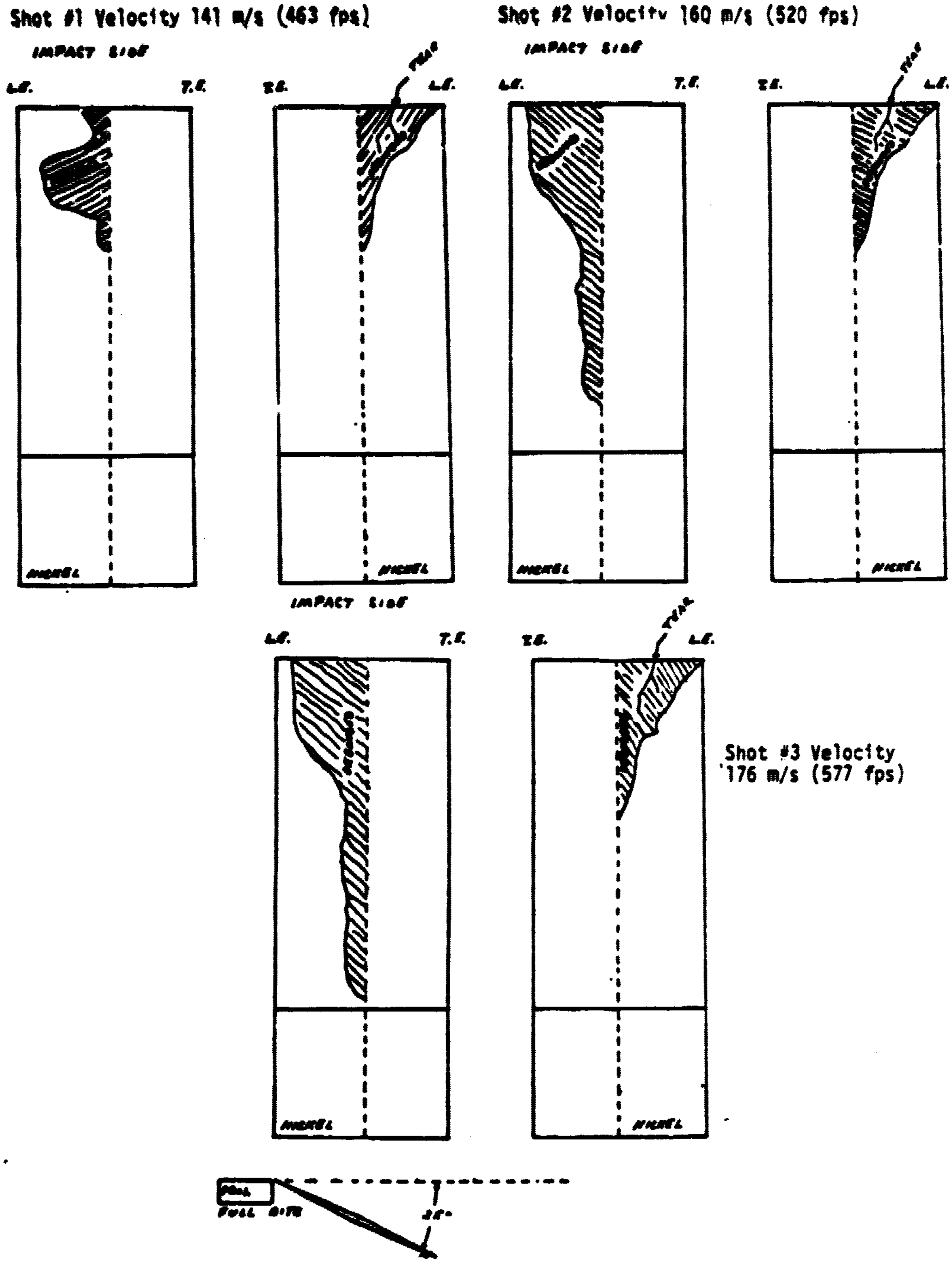


Figure 89. Superhybrid Specimen (SPIII-13) Impact Damage Tested at 394 K (250° F) Wet.

Shot #5 Velocity 22 m/s (723 fps)　　　　Shot #4 Velocity 202 m/s (663 fps)

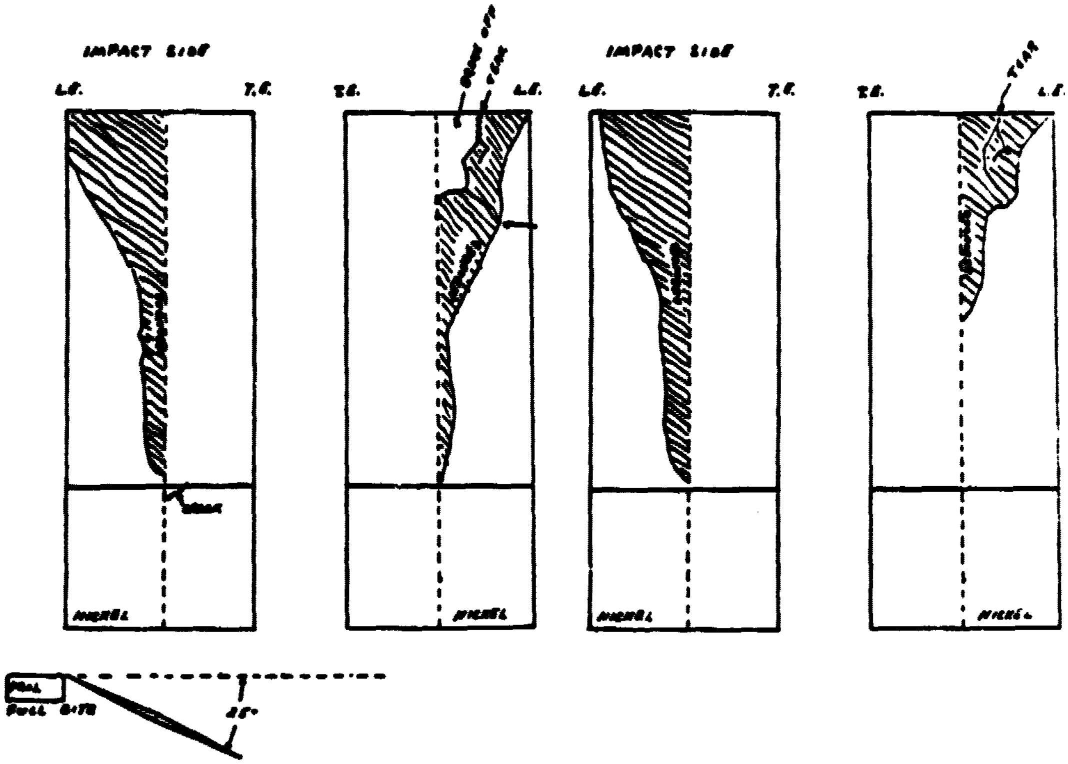


Figure 90. Superhybrid Specimen (SPIII-13) Impact Damage Tested at 394 K (250° F) Wet.

PMRF-26 250°F Wet

Shot #2 Velocity 161 m/s (529 fps)

Shot #3 Velocity 185 m/s (606 fps)

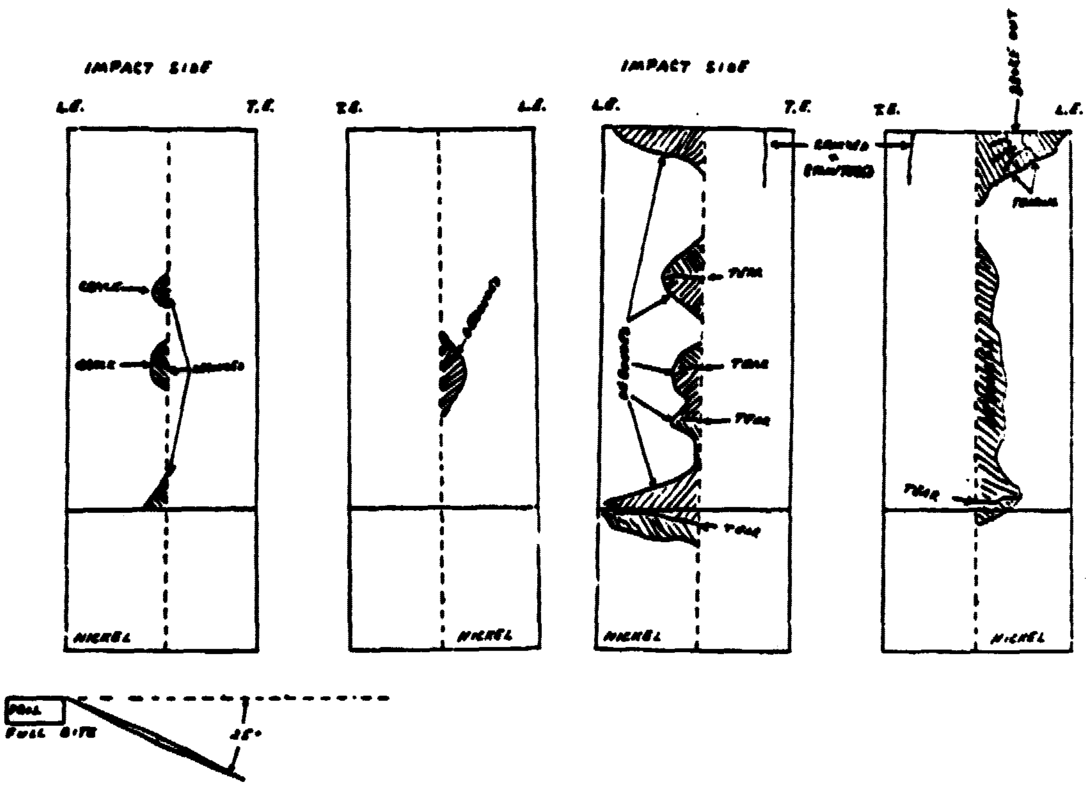


Figure 91. Hybrid Specimen (PMRF-26) Impact Damage Tested at 394 K (250° F) Wet.

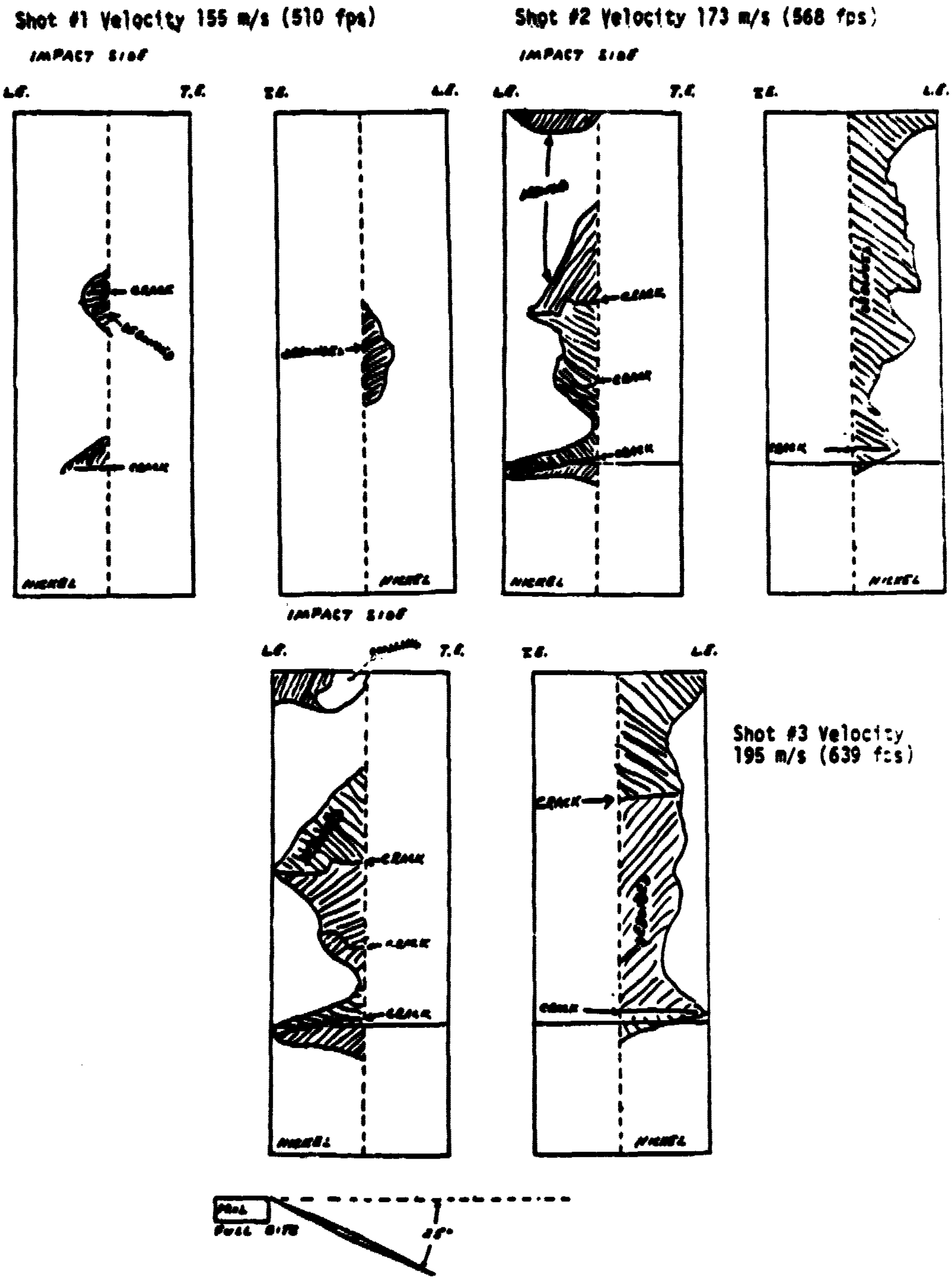


Figure 92. Hybrid Specimen (PMRF-27) Impact Damage Tested at 394 K (250° F) Wet.

through 92, 394 K (250° F) 'wet' condition. Premature unbonding of the leading edge protection was not classified as failure and the velocity of the projectile was increased until damage occurred in the composite airfoil section.

Moisture degradation of the Metlbond 328 adhesive, used to bond the wire mesh plating substrate, was suspected to be the primary cause of the premature bond failure coupled with the high peel forces induced during the extreme flexing and twisting of the essentially flat plate-like specimen during impact.

Each specimen was subjected to posttest ultrasonic C-scan inspection prior to evaluating the loss in torsion stiffness. A complete summary of the ultrasonic inspection records and the impact data are shown in Tables XCVI through CV.

5.7 IMPACT DATA EVALUATION RESULTS AND CONCLUSIONS

The purpose of the impact testing in Task III was to determine the effects of environmental conditioning on the ballistic impact damage characteristics of simulated airfoil specimens which included a leading edge protection device.

Unlike the testing in Task II, the impact velocity of the projectile was increased progressively to assess the damage threshold level of each design specimen. Multiple impacts were conducted on each specimen at velocities ranging from 120 to 275 m/sec (400 to 900 ft/sec) utilizing a simulated starling size gelatin "bird" of ~85 grams.

Premature failure of the nickel/wire mesh leading edge protection device unfortunately overshadowed the test results on nearly all the twenty panels tested. Failure analysis of the leading edge protection indicated that 80 percent of the delamination had occurred at the wire mesh to composite interface and was cohesive type failure in the Metlbond 328 adhesive. The remaining 20 percent was associated with poor adhesion between the nickel plate to wire mesh, probably caused by poor surface activation prior to electroplating. The nickel plate was also brittle with many of the specimens showing early signs of cracking and spallation.

Despite the leading edge problems, an attempt was made to characterize the data in terms of threshold damage level by comparing percentage delamination versus normal impact energy for both the leading edge protection and that sustained on the hybrid or superhybrid composite. These data are summarized in Figures 93 through 97.

The observations and qualitative conclusions for this data are:

- The superhybrid (SPIII series) and the hybrid (PMRF series) specimens tested at 219 K (-65° F) condition indicated good correlation and least inconsistency from any other test condition.

Table XCVI. Task III Specimen Impact Data and Inspection Records.

			Non-Destructive Inspection				Impact Data		
Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Initial C-Scan	Hand Scan After Impact	Final Scan	Visual Damage	Velocity m/sec (ft/sec)	Slice Size GMS	Normal Impact Energy Joules (ft/lb)
SP313 Superhybrid									
(2-0546)	Dry	219 K (-65° F)	Small areas of porosity indications in initial C-scan	No damage indicated.	Delamination of L.E. protection under clamp	No visual damage.	144(583)	72.5	134(99)
(2-0547)				Delamination of Ni of 6.5 cm^2 (1 in.^{2}) opposite side.		Nickel protection lifted at tip opposite side.	178(583)	76.9	216(159)
(2-0548)				No change.	Delamination in composite ground crack at clamp and around wrinkle in foil at impact zone.	No increase damage	215(705)	83.1	340(251)
(2-0549)				Nickel has 12.9 cm^2 (2 in.^{2}) disbond at tip on impact side. Nickel is 95% disbonded opposite side of impact.		10 cm (4 in.) crack at clamp on impact side	236(774)	75.8	374(276)
(2-0550)				Impact side has 20% disbonded nickel at tip and at impact zone.		Impact side has crack completely across at clamp and 6.5 cm^2 (1 in.^{2}) lifted composite at tip.	267(876)	82.4	521(384)
SP313 Superhybrid									
SPIII-7 (2-0551)	Dry	219 K (-65° F)	No indication in initial C-scan	No damage indicated	Delamination in L.E. protection and in composite around crack at clamp, and around radial crack just above impact zone.	No visual damage	177(582)	80.1	226(165)
(2-0552)				No damage.		No damage	215(706)	75.7	311(229)
(2-0553)	Dry	219 K (-65° F)	No indication in initial C-scan	Nickel delaminated over 50% area opposite impact side. Foil delamination across tip on impact impact side 32 cm^2 (5 in.^{2}).		L.E. protection disbond opposite impact, and foil feel back at tip on impact side.	242(795)	84.5	439(324)
(2-0554)				Side opposite impact has increase nickel delamination to 60% plus foil delamination of 40% impact side has foil delamination of 30% at T.E. tip and Ni disbond at impact and clamp of 26 cm^2 (4 in.2)		Side opposite impact has nickel and foil delamination plus axial (crack 10 cm (4 in.) long 2.5 cm (1 in.) from T.E. Impact side has foil and Ni disbond plus 13 cm (5 in.) crack along 1 clamp.	279(914)	83.1	571(421)

Table XCVII. Task III Specimen Impact Data and Inspection Records.

			Non-Destructive Inspection				Impact Data		
Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Initial C-Scan	Hand Scan After Impact	Final Scan	Visual Damage	Velocity m/sec (ft/sec)	Slice Size GMS	Normal Impact Energy Joules (ft/lb)
SP313 Superhybrid									
(2-0522)	Dry	394 K (250° F)	No initial indication protection has caused some masking.	Disbond of L.E. protection on impact side of 58 cm^2 (9 $in.^2$) center 7.6 cm (3 $in.^2$) from tip.	65% delamination of L.E. protection.	Disbonding of Ni on impact side consisting of 256% of total exposed area.	157(514)	77.3	168(124)
(2-0523)				Disbonding increased to 6.5 cm^2 (10 in^2)		Slight increase of disbond towards impact zone.	183(601)	82.2	244(180)
(2-0524)				Continue disbonding to 97 cm^2 (15 $in.^2$) on impact side and 26 cm^2 (4 $in.^2$) on opposite side.		L.E. protection disbond to impact zone with added disbonding on opposite side near tip.	204(669)	84.1	311(229)
(2-0525)				Increase disbonding on both sides to 161 cm^2 (25 $in.^2$) of total.		75% of Ni above impact zone is disbonded.	235(772)	78.7	386(285)
(2-0526)				232 cm^2 (36 $in.^2$) of disbonded L.E. protection.		In addition to disbonding, three small tears have started in nickel.	265(870)	83.7	521(384)
(2-0527)				Slight increase in Nickel disbonding.		19 cm^2 (3 $in.^2$) of nickel has spalled away behind impact zone.	277(909)	83.8	570(420)
PMR15 Hybrid									
(2-0528)	Dry	394 K (250°F)	Slight indications of porosity at each end.	Nickel delamination over 50% area opposite impact side.	Nickel delamination of 85% - composite delamination of 19 cm^2 (3 $in.^2$) at T.E. tip and T.E. across from impact.	A band of Nickel has delaminated 3.8 cm (1-1/2 in.) wide from tip to clamp opposite impact side.	156(513)	79.1	171(126)
(2-0529)				Nickel delamination increased to 60%.		Band of delaminated Ni and tip.	178(585)	77.9	220(162)
(2-0530)				Slight increase in delam. to 70%.		Increase in delamination plus slight composite splintering at T.E.	199(654)	83.0	293(216)
(2-0531)				Nickel delamination 85% opposite impact side, and 5% on impact side.		Continue delamination plus new start at corner on impact side. Also composite missing 6.5 cm^2 (1 $in.^2$) plus radial crack 2.5 cm (1 in.) long in line with impact.	227(746)	80.1	367(271)

Table XCVIII. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection: Initial C-Scan	Non-Destructive Inspection: Hand Scan After Impact	Non-Destructive Inspection: Final Scan	Non-Destructive Inspection: Visual Damage	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size CMS	Impact Data: Normal Impact Energy Joules (ft/lb)
SP313 Superhybrid									
(2-0535)	Dry	294 K (70° F)	Slight porosity at each end in max "t" area.	No damage indication.	80% delamination of L.E. protection. 20% delamination of composite other than L.E. area.	No visual damage.	166(546)	72.8	179(132)
(2-0536)				No damage.		No damage.	192(630)	77.5	254(187)
(2-0537)				Foil on impact side disbonded 0.9 cm x 0.9 cm (3/8 in. 3/8 3/8 in.)		Foil disbonded on T.E. tip.	217(712)	77.1	231(237)
(2-0538)				Disbond increase to 3 x 5 cm (1-1/4 in. x 2 in.).		Foil on T.E. tip continue to lift.	245(803)		
(2-0539)				Composite delaminated at tip 77 cm^2 (12 in.^{2}) on each side.		Ni is lifted at tip on each side has a bulge 9.7 cm^2 (1-1/2 in.^{2}) 15 cm (6 in.) down from tip.	274(900)	84.2	561(414)
(2-0540)				Increased delamination to 355 cm^2 (55 in.^{2}) on each side.		Bulge in nickel increased 26 cm^2 (4 in.^{2})	285(936)	81.3	586(432)
SP313 Superhybrid									
(2-0541)	Dry	294 K (70° F)	Indications of porosity in initial C-scan.	No damage indicated	Delaminations of 19 cm^2 (3 in.^{2}) outside L.E. protection above clamp.	No visual damage.	194(635)	77.0	255(188)
(2-0542)				No damage.		No damage.	212(694)	79.8	316(233)
(2-0543)				No damage.		No damage.	237(779)	83.6	418(308)
(2-0544)				Delamination of Nickel opposite of impact side.		Ni protection has lifted and bulged over 3.9 cm^2 (6 in.^{2})	---	---	---
(2-0545)				Increased delamination on opposite side to impact side to 77 cm^2 (12 in.^{2}). Impact side has 13 cm^2 (2 in.^{2}) of delamination.		Crack completely across impact side at clamp.	288(944)	78.4	575(424)

Table XCIX. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection: Initial C-Scan	Non-Destructive Inspection: Hand Scan After Impact	Non-Destructive Inspection: Final Scan	Non-Destructive Inspection: Visual Damage	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size GMS	Impact Data: Normal Impact Energy Joules (ft/lb)
PMR15 Hybrid									
(2-0696)	Dry	294 K (70° F)	Slight indications of porosity.	No damage.	80% delamination of L.E. Protection	No damage.	152(500)	78.7	161(119)
(2-0697)				Protection debonded 50% both sides.	13 cm (2 in.^{2}) delamination of composite at T.E. tip.	Nickel protection debonded 50% both sides from clamp to tip.	165(542)	82.65	199(147)
(2-0698)				Protection debonded area increased to 75% both sides.		Debond area increased and tears developed in Ni.	183(602)	83.9	251(185)
(2-0699)				Debond area increased and delamination in composite around cracks at clamp and T.E.		Increased debonding of L.E. protection crack in composite at clamp and T.E. cracked an/ splintered.	199(654)	83.3	293(216)
PMR15 Hybrid									
(2-0684)	Dry	294 K (70° F)	Slight indication of porosity at ends.	No Damage	Delamination of L.E. protection 32 cm^2 (5 in.^{2}) composite delamination 26 cm^2 (4 in.^{2}) composite delamination 26 cm^2 (in.^{2}).	No damage	119(390)	74.0	92(68)
(2-0685)				13 cm^2 (2 in.^{2}) debond of protection edge.		Slight disbond and buckling 5 x 1.6 cm (2 in. x 5/8 in.) area Opposite side to impact.	143(470)	74.0	134(99)
(2-0686)				No further detectable damage.		No increase in damage to Nickel plate	152(499)	75.7	155(114)
(2-0687)				Slight propagation of debond area of Ni plate.		Slight increase in debonding area 6.5 cm^2 (1 in.^{2}) debond area on impact side.	167(549)	84.0	209(154)
(2-0688)				Increased disbonding of Ni plate protection.		Debond are increase 11 x 1.6 cm (4-1/2 in. x 5/8 in.) on [illegible] side. [illegible] debond areas 6.5 cm^2 (1 in.^{2}) on impact side.	184(605)	74.0	222(164)
(2-0689)				Delamination of composite tip T.E. area increased debonding of plated protection.		Three [illegible] areas on impact [illegible]. Delamination of tip T.E. in composite T.E. cracked at clamp.	203(667)	80.1	293(216)
(2-0690)				Further delamination of composite tip. Additional 6.5 cm^2 (1 in.^{2}) debond area on impact side.		Increased delam. of T.E. composite and corner broken away. Additional debonding of Ni plate composite splintered from impact zone to tip.	213(699)	80.95	352(260)

Table C. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection				Impact Data		
			Initial C-Scan	Hand Scan After Impact	Final Scan	Visual Damage	Velocity m/sec (ft/sec)	Slice Size GMS	Normal Impact Energy Joules (ft/lb)
SP313 Superhybrid									
(2-0478)	Wet	294 K (70° F)	No C-scan indication but L.E. protection has masked any indication in that areas	L.E. protection disbonded over 75% area above clamp-both sides.	Disbond in L.E. protection.	Axial crack in protection on opposite side to impact. Radial crack in nickel at tip 7cm (2.75 in.) long.	211(693)	64.0	254(187)
SP313 Superhybrid									
(2-0479)	Wet	294 K (70° F)	No C-scan indication except in L.E. protection.	L.E. protection disbonded at tip downstream corners 2.5 x 6.4 cm (1 in. x 2-1/2 in.) impact side and 5 x 6.4 cm 6.(2 x 2-1/2 in.) on reverse side.	Disbond in L.E. protection. No disbonds indicated in composite area.	Protection disbonded at tip both sides. Triangular disbond at corners. No composite damage.	121(398)	55.4	72(53)
(2-0480)				L.E. protection disbond area increased 2.9 x 6.4 cm (1-1/8 x 2-1/2 in.) impact side and 8.3 cm (3-1/4 in.) on reverse side.		Protection disbond area increased slightly. No composite damage.	136(445)	70.0	179(84)
(2-0481)				L.E. protection disbond area increased 4.1 x 13 cm (1-5/8 x 5-1/4 in.) impact side and 27 x 7.6 cm (10-1/2 x 3 in) on reverse side.		Protection disbond area further increased down the blade length both sides. No composite damage.	165(541)	74.5	179(132)
(2-0482)			LE is masked. No other indication.	Protection disbonding increased 50% of area from clamp to tip on impact side and 25% area on reverse side.	Delamination of L.E. No other indications.	Further disbonding of protection. Ni plate cracked at the clamp on impact side. No composite damage.	169(553)	79.6	201(148)
(2-0483)				Protection disbonded 75% area on impact side and 50% on reverse side.		Debonding area increased both sides. Loose Ni tore at tip 6.4 cm (2-1/2 in.) long. No composite damage.	193(631)	76.6	251(185)

Table CI. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection: Initial C-Scan	Non-Destructive Inspection: Hand Scan After Impact	Non-Destructive Inspection: Final Scan	Non-Destructive Inspection: Visual Damage	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size GMS	Impact Data: Normal Impact Energy Joules (ft/lb)
PMR15 Hybrid									
(2-0491)	Wet	294 K (70° F)	No indicaitons, L.E. protection has caused some masking.	No damage.	Delamination of L.E. protection at tip. Delamination of composite around	No damage.	90(294)	63.3	45(33)
(2-0492)				No damage.		No damage.	163(535)	76.7	180(133)
(2-0493)				Debonded area extending from 5.7 cm (2-1/4 in.) long crack in protection to T.E.		Ni cracked 0.6 cm (1/4 in.) above clamp impact side.	161(528)	83.7	193(142)
(2-0494)				Debond area increased following nickel crack.		Crack in Ni propagated to L.E. 1 cm (3/8 in.) lon radial crack in composition T.E. zone and crack at clamp in composite.	188(616)	84.0	263(194)
(2-0495)				Protection debonded at tip both sides. T.E. delaminated 10 cm (4 in.) down from tip on reverse side.		Composite cracked and splintered at clamp. Ni plate debonded at tip. Composite delaminated at tip T.E.	204(668)	82.6	304(224)
SP313 Superhybrid									
(2-0511)	Dry	394 K (250° F)	No initial C-scan indications.	No damage.	Delamination of 58 cm^2 (9 in.^{2}) in composite outside L.E. protection-90% L.E. protection indicates delamination.	No damage.	142(465)	81.1	144(106)
(2-0512)				No damage.		No damage.	155(508)	72.9	155(114)
(2-0513)				No damage.		No damage.	180(590)	77.9	222(164)
(2-0514)				Slight delamination in composite T.E. tip and debond of protection at the tip.		Slight debond at T.E. tip of protection and at T.E. tip of composite.	202(662)	79.7	287(212)
(2-0515)				No change from previous hand scan.		No change	214(702)	83.0	336(248)
(2-0516)				Increase debonding of Ni and foil, 6.5 cm^2 (1 in.^{2}) debond of L.E. impact zone.		Slight increase in delam. at tip and debonding of protection, slight debond area in impact zone.	236(775)	78.8	389(287)
(2-0517)				No further damage indication.		No further damage noted.	241(792)	82.2	424(313)
(2-0518)				Completely disbonded from impact zone to bottom of specimen on each side.		Delam. in composite from impact zone to bottom of specimen, crack at clamp.	251(825)	81.2	456(336)

Table CII. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection: Initial C-Scan	Non-Destructive Inspection: Hand Scan After Impact	Non-Destructive Inspection: Final Scan	Non-Destructive Inspection: Visual Damage	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Stic Size GMS	Impact Data: Normal Impact Energy Joules (ft/lb)
PMR15 Hybrid									
(2-0555)	Dry	219 K (-65° F)	No indication in initial C-scan	Nickel delamination. $13 cm^2$ ($2 in.^2$) impact side.	Delamination in L.E. protection of 25% - composite delamination of $26 cm^2$ ($4 in.^2$) trailing edge tip and 19 cm ($3 in.^2$) around crack at clamp	Nickel disbond center $7.6 cm^2$ ($3 in.^2$) from tip.	158(517)	80.0	176(30)
(2-0556)				Increased delamination to $19 cm^2$ ($3 in.^2$).		Slight increase in Ni disbond.	186(610)	81.2	248(183)
				Delamination increased to $26 cm^2$ ($4 in.^2$) plus $13 cm^2$ ($2 in.^2$) Delamination of Ni on side opposite impact.		Disbond of Ni both sides plus T.E. crack at tip and at clamp.	221(725)	80.0	346(265)
(2-0558)				Ni delamination of $45 cm^2$ ($7 in.^2$) on impact side and $32 cm^2$ ($5 in.^2$) on opposite side		Increase Ni delamination both sides plus increase cracking and 25 x 10cm(1" x 4") section of composite broken off at T.E. tip.	243(796)	82.3	430(317)
PMR15 Hybrid									
(2-0559)	Dry	219 K (-65° F)	No indication except in L.E. Protection.	No Damage	90% disbond of L.E. protection composite delamination of $26 cm^2$ ($4 in.^2$) at T.E. tip and $13 cm^2$ ($2 in.^2$) around crack at clamp	No Damage	153(501)	82.0	169(125)
(2-0560)				No Damage		No Damage	176(578)	83.7	231(170)
(2-0561)				Nickel disbond oposite impact side.		Corner of Ni has lifted a tip on side opposite of impact plus composite cracks 2.5 cm (1 in.) long on T.E.	210(668)	80.9	315(232)
(2-0562)				Increase nickel disbond to $19 cm^2$ ($3 in.^2$)		Composite cracks at T.E. tip 5 cm (2 in.) long composite piece broken off 1.3 x 5 cm (1/2 x 2 in.) 7.6 cm (3 in.) from tip. Crack at clamp 6.35 cm (2-1/2 in.) long.	247(810)	82.1	443(327)

Table CIII. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection: Initial C-Scan	Non-Destructive Inspection: Hand Scan After Impact	Non-Destructive Inspection: Final Scan	Non-Destructive Inspection: Visual Damage	Impact Data: Velocity m/sec (ft/sec)	Impact Data: Slice Size GW.	Impact Data: Normal Impact Energy Joules (ft/lb)
PMR15 Hybrid									
(2-0532)	Dry	394 K (250° F)	Porosity at max. 'T' both ends and in L.E. protection.	Nickel delamination of 40% on each side.	Nickel delamination of 75% - Some delamination of composite. T.E. (incomplete scan)	Nickel delamination with 2.5cm(1") long	158(518)	67.9	151(111)
(2-0533)				Nickel delamination of 50% on each side (60% on area from tip to clamp)		Increase delamination and cracking of nickel, Ni now has 5 cracks.	177(582)	83.8	233(172)
(2-0534)				Increase nickel delamination to 70% each side.		Increase cracks and spalling of nickel, composite damage on T.E. 5 x 0.6cm(2" x 1/4") missing area & two cracks 2.5 cm (1") long.	202(664)	76.9	279(206)
SP313 Superhybrid									
(2-0500)	Wet	394 K (250° F)	No C-scan indication but L.E. is masked with L.E. protection.	Debonded area of protection 50% on reverse side. T.E. corner tip delamination 3.8 x 3.8 cm (1-1/2" x 1-1/2").		Protection debonded over 50% area on reverse side T.E. tip delamination 6.5 cm^2(1 $in.^2$).	151(494)	81.9	164(121)
(2-0501)				Nickel debonded over 50% on both sides T.E. composite delaminated.		Protection debonded on both sides over 50% area nickel spalled at tip on reverse side separated from wire mesh.	177(581)	80.9	225(166)
(2-0502)				Further debonding of wire/nickel over 75% on both sides.	75% of L.E. protection disbonded. No other indications.	Increase debonding and Ni wire separation tears in nickel plate.	187(615)	82.0	255(188)

Table CIV. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection				Impact Data		
			Initial C-Scan	Hand Scan After Impact	Final Scan	Visual Damage	Velocity m/sec (ft/sec)	Slice Size GMS	Normal Impact Energy Joules (ft/lb)
SP313 Superheld									
(2-0503)	Wet	394 K (250° F)	No C-scan indication but L.E. is masked with L.E. protection.	L.E. protection debonded over 25% of area from mid span to tip.	$1.6 cm^2$ ($1/4 in.^2$) delamination is just outside the masking effect of the L.E. protection.	Protection debonded from impact site tip and at tip on reverse side.	141(463)	82.1	145(107)
(2-0504)				L.E. protection debonded over 40% of area.		Further debonding of edge of L.E. protection tear in nickel at the tip.	160(526)	84.0	191(141)
(2-0505)				L.E. protection debonded over 50% area.		Progressive debonding of L.E. protection down to clamp.	176(577)	82.2	225(166)
(2-0506)				Slight increase in debonded area of L.E. protection.		Further debonding.	202(663)	75.4	273(201)
(2-0507)				Increased debonding area. No delamination noted in composite.		Further debonding, developed crack in outer foil layer at clamp, nickel corner broke away.	220(723)	79.5	342(252)
PMR15 Hybrid									
(2-0508)	Wet	294 K (70° F)	No C-scan indication, some masking cause by L.E. protection.	No damage	Delamination of L.E. protection at tip and clamp $6.5 cm^2$ ($1 in.^2$) composite delamination around cracked areas.	No damage.	134(441)	77.9	125(92)
(2-0509)				Three debond areas $6.5 cm^2$ ($1 in.^2$) at T.E. of protection.		Protection commencing to debond in three localized areas on impact side and one on reverse side, crack in Ni at two places.	161(529)	75.4	174(128)
(2-0510)				30% debond of L.E. protection, delamination of T.E. at tip around crack.		Increase debonding and spalling of Ni on reverse side tears in Ni, T.E. crack and splintered.	185(606)	83.0	251(185)

Table CV. Task III Specimen Impact Data and Inspection Records.

Specimen No. (Shot No.)	Envir. Condition	Impact Test Temperature	Non-Destructive Inspection				Impact Data		
			Initial C-Scan	Hand Scan After Impact	Final Scan	Visual Damage	Velocity m/sec (ft/sec)	Slice Size GMS	Normal Impact Energy Joules (ft/lb)
PMR15 Hybrid									
(2-0519)	Wet	394° K (250° F)	No initial indication, but L.E. is masked with nickel protection.	Nickel protection has disbonds at impact and clamp areas.	75% delamination of L.E. protection. 6.5cm^2(in.^{2}) composite delamination across from impact.	Radial cracks in nickel at impact and clamp.	155(510)	70.9	152(112)
(2-0520)				Each side of nickel has 40% debond area.		Three cracks are present on impact side and one crack on opposite side at clamp.	173(568)	74.3	198(146)
(2-0521)				Nickel is disbonded over 50% of total area on both sides.		Four cracks have increase in length in nickel on impact side and opposite side has two cracks.	195(639)	84.0	282(208)

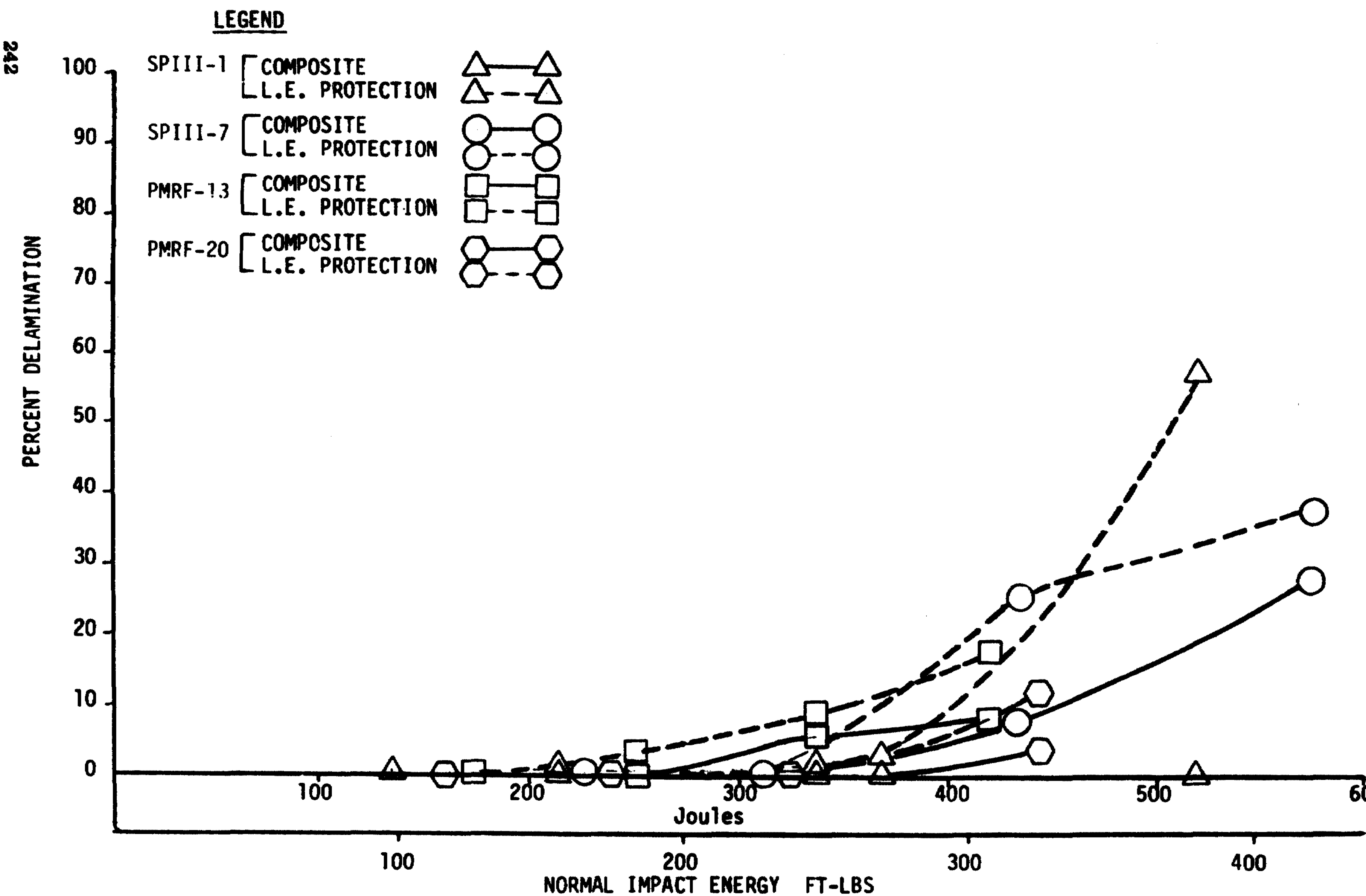


Figure 93. Impact Energy/Delamination Correlation Test Condition 219 K (-65° F) Dry.

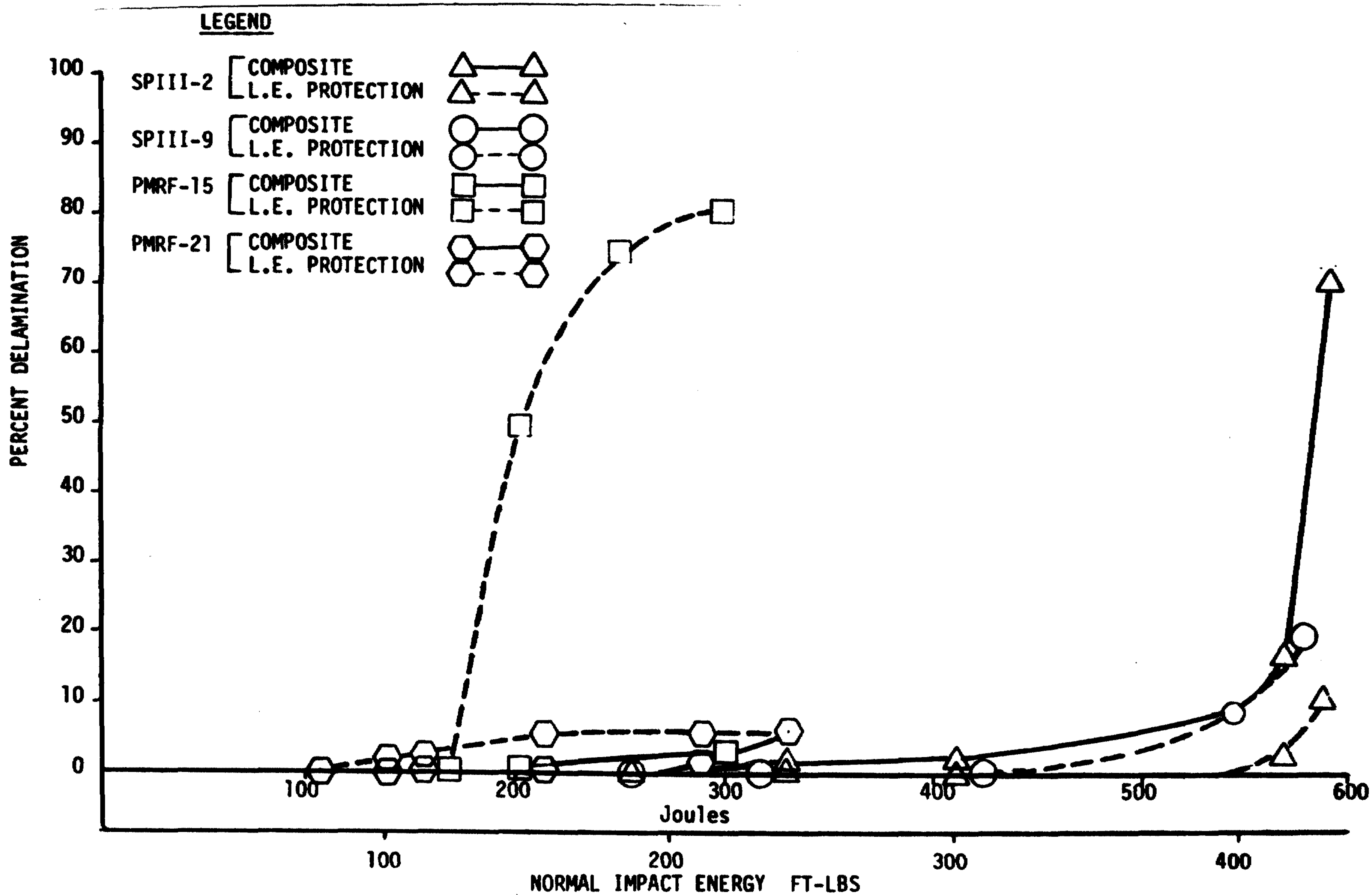


Figure 94. Impact Energy/Delamination Correlation Test Condition 294 K (70° F) Dry.

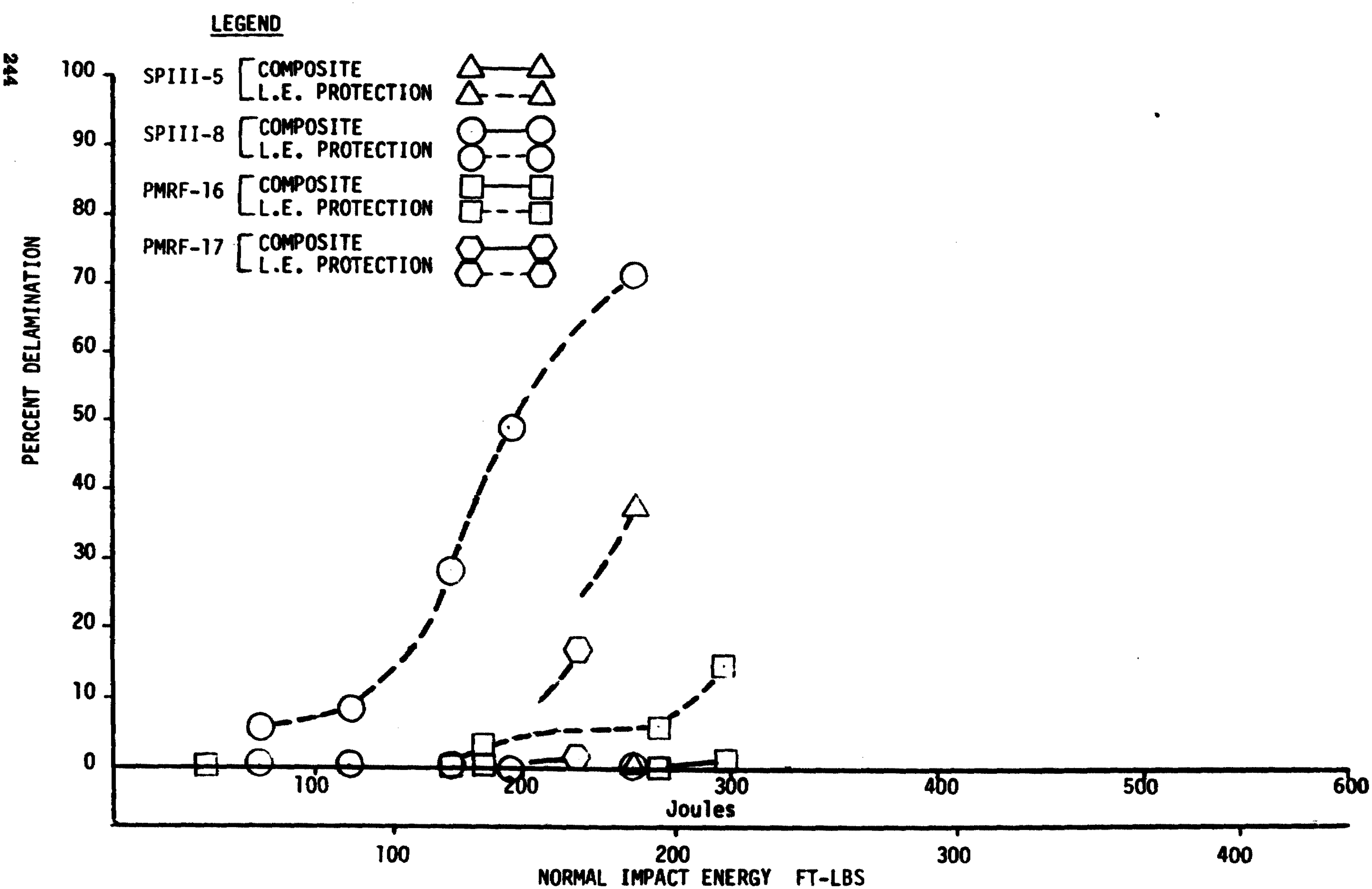


Figure 95. Impact Energy/Delamination Correlation Test Condition 294 K (70° F) Wet.

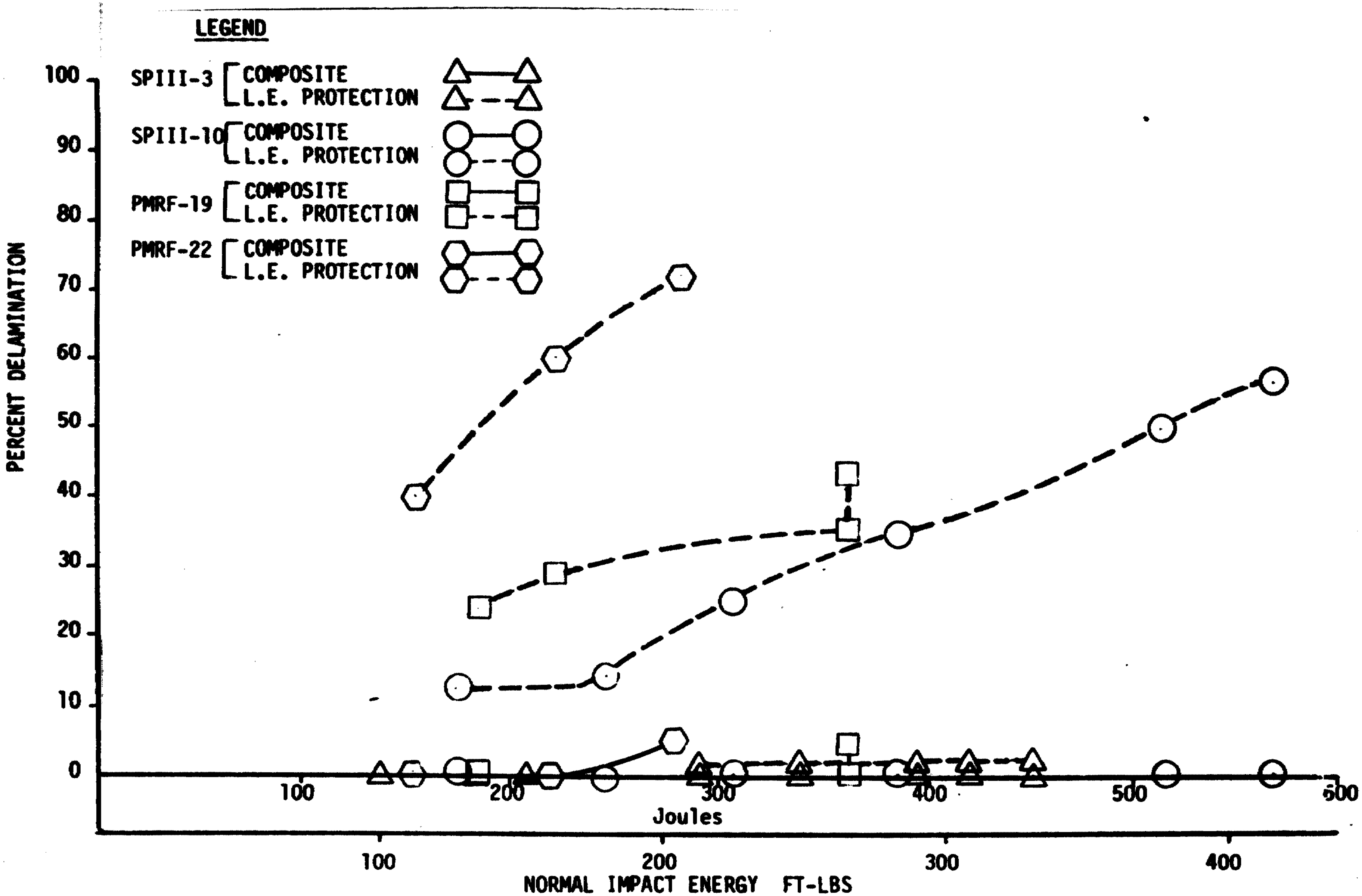


Figure 96. Impact Energy/Delamination Correlation Test Condition 394 K (250° F) Dry.

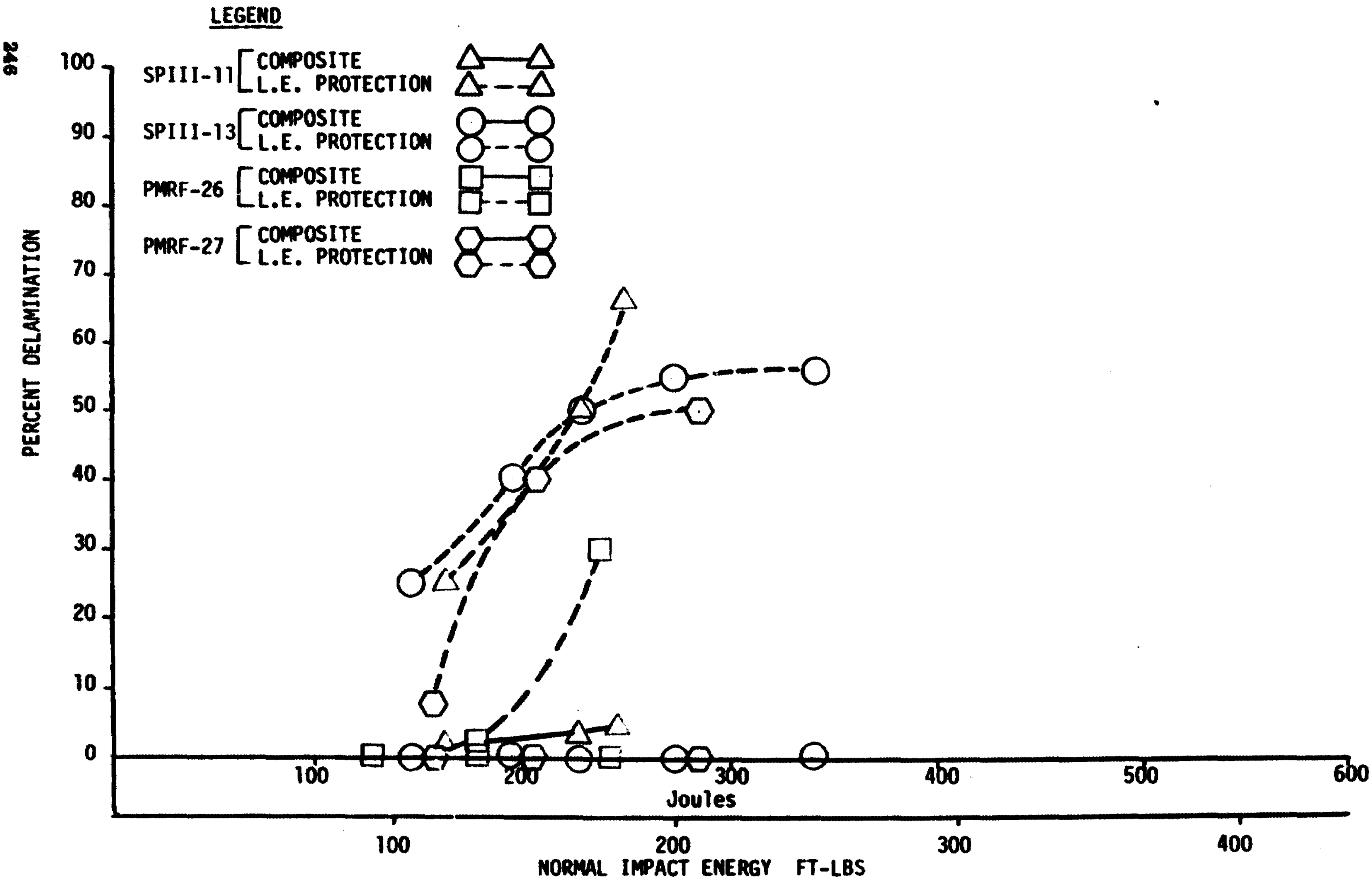


Figure 97. Impact Energy/Delamination Correlation Test Condition 394 K (250° F) Wet.

- The threshold damage level to the composite substrate, tested at 219 K (-65° F) appeared higher for the superhybrid specimens [≈380 joules (≈280 ft-lb)] compared to the hybrid specimens [≈227 joules [≈200 ft-lb)].

- The failure of the leading edge adhesive at the wire to composite interface, occurred at a lower energy level and produced higher damage levels for the wet condition specimens when tested at both 294 K (70° F) and 394 K (250° F). Moisture degradation of the Metlbond 328 adhesive is deemed to be the premature cause of the bond failure.

- Damage to the composite substrates for all test conditions was generally of low magnitude (below 5 percent delamination area) with little or no indication of being more severe for wet versus dry conditions.

- Composite damage was almost entirely confined to the trailing edge of the specimen, especially at the free tip section. The hybrid composite specimens exhibited initial radial cracks and the superhybrid specimens foil delamination in this zone.

- Fifty-five percent of all the specimens exhibited cracks in the zone of the support clamp intersection. Sixty percent of the superhybrid and fifty percent of the hybrid specimens showed early signs of failure commencing in this area. Cracks in the clamp zone were less prevalent in the specimens tested at the elevated temperature. This was attributed to the softening of the adhesive and distributing the stress concentration at the sharp intersection.

- Ranking the specimens by test condition and by design (hybrid versus superhybrid) as shown in Table CVI indicates the superhybrid design to be superior at all test temperatures and environmental conditions. The ranking was accomplished by comparing the normal impact energy required to initiate damage to the composite substrate.

Table CVI. Task III Specimen Ranking by Test Condition and by Design.

Test Condition	Ranking Specimen / Design	Hybrid				Superhybrid			
		Specimen No. 1		Specimen No. 2		Specimen No. 1		Specimen No. 2	
219 K(-65°F) "Dry"	Specimen	PMRF-20	3	PMRF-13	4	SPIII-1	1	SPIII-7	2
	Design	2				1			
294 K(70°F) "Dry"	Specimen	PMRF-21	3	PMRF-15	4	SPIII-9	1	SPIII-2	2
	Design	2				1			
294 K(70°F) "Wet"	Specimen	PMRF-16	3	PMRF-17	4	SPIII-8	1	SPIII-5	2
	Design	2				1			
394 K(250°F) "Dry"	Specimen	PMRF-19	3	PMRF-22	4	SPIII-10	1	SPIII-3	2
		2				1			
394 K(250°F)	Specimen	PMRF-27	2	PMRF-26	4	SPIII-11	3	SPIII-13	1
		2				1			

6.0 TASK IV - SIMULATED BLADE SPIN IMPACT TESTS

The basic purpose of Task IV was to conduct dynamic whirligig impact testing on similar moisture conditioned specimens to the designs used for the Task III static impact evaluation.

A specimen rig fixture was designed and four sets of the titanium specimen adaptor shoes (outserts) were procured. The assembly shown in Figure 98 consists of an existing whirligig disk and trunnion, a locating plate to provide the 25 degrees incidence angle and a pair of dovetail outserts bonded to the composite specimens. Two transverse clamping bolts were provided to hold the specimen between the outserts during the bonding operation.

6.1 SPECIMEN FABRICATION

All the Task IV specimens were manufactured in parallel with the Task III specimens and were allocated to the specific test temperature matrix as shown in Table CIV.

6.2 ADHESIVE EVALUATION

Preliminary bonding trials were conducted to determine the procedure for bonding the titanium rig adaptor shoes to the test specimens. In order to prevent moisture degradation during conditioning of the Metlbond 328 bonding adhesive, as experienced in Task III leading edge bonding, the exposed titanium shoe/specimen bondline was planned to be sealed with a silicone RTV rubber.

A series of titanium lap shear specimens were prepared to determine the effectiveness of RTV silicone rubber as a moisture barrier to prevent degradation of the Task IV specimen bond to the titanium rig adaptor shoes during moisture conditioning. The 2.54 cm (1 in.) wide by 1.25 cm (0.5 in.) overlap single lap shear specimens were bonded with the selected adhesive Metlbond 328. The silicone rubber (RTV 106) was applied as a bead over the exposed bond line and allowed to fully cure. The specimens were humidity conditioned at 355 K(180° F)/97% relative humidity. Preliminary indications after seven days humidity exposure was that the RTV silicone rubber appeared to be acting as an effective moisture barrier. Table CVII lists the test specimen results obtained after seven and forty-two days exposure. Forty-two days was "full saturation" condition based upon the PMR15 unprotected Task III specimen. The forty-two day exposure tests, however, indicated (for this adhesive) that the moisture is slowly permeating through the RTV film barrier, and eventually, will reach full saturation. The moisture saturation after forty-two days severely degraded lap shear properties retaining only 15 percent strength on the exposed bondline specimens and 40 percent strength on the RTV protected specimens when tested at 394 K(250° F).

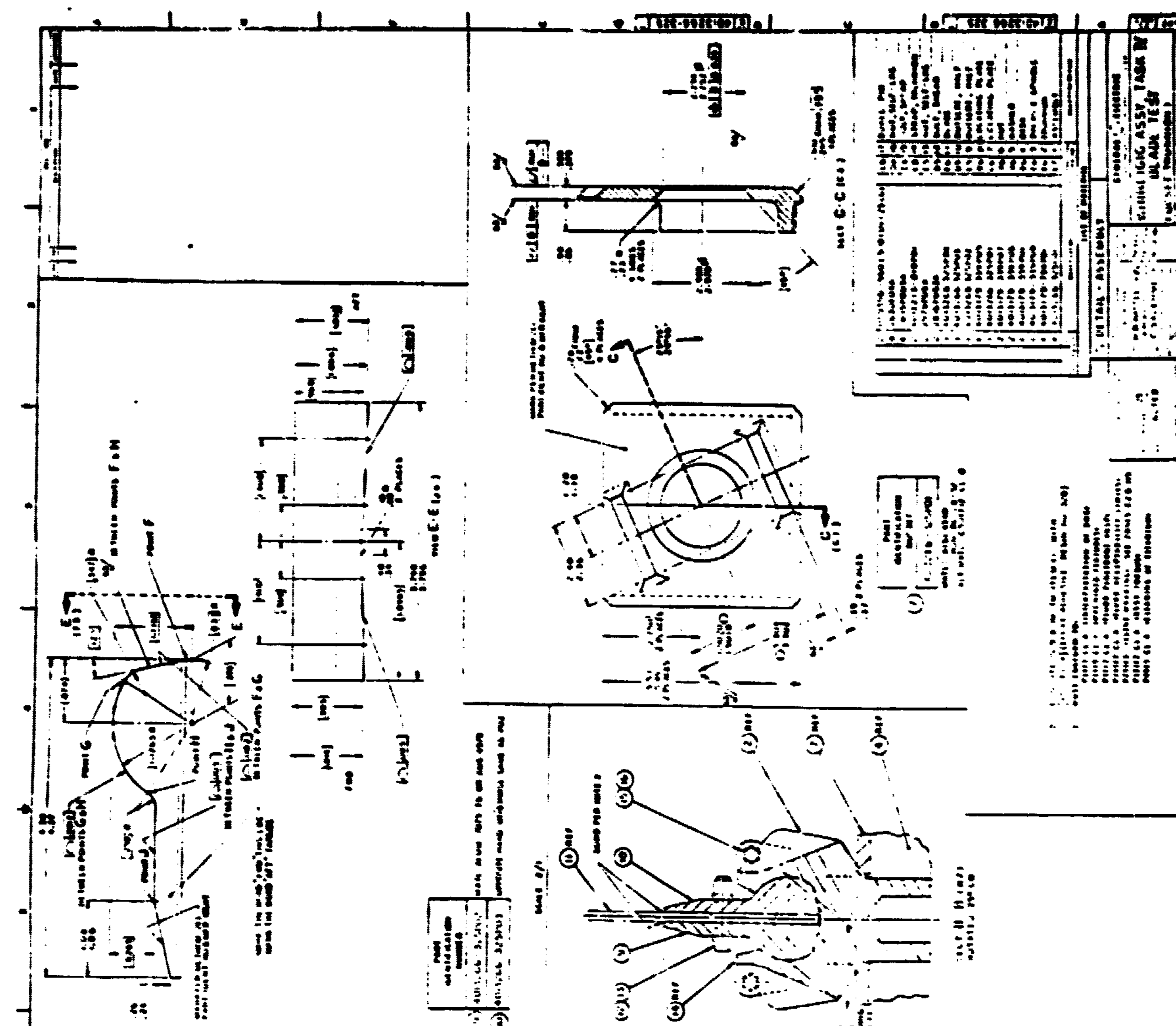


Figure 98. Whirligig Assembly Blade Test Adaptor.

Table CVII. Metlbond 328 Adhesive Tests.

Effects of RTV Silicone Rubber Barrier During Moisture Conditioning

Specimens Conditioned for 7 Days at 355 K (180° F)/97% RH

Specimen Design	Test Temperature °K(°F)	Shear Strength MPa(psi)		Type of Failure
		12.96(1880)		90% Adhesive
Unprotected	394 K(250°F)	4.62(670)		100% Adhesive
		8.83(12.80)	Avg.	
Protected with		16.0 (2320)		15% Adhesive
RTV Silicone	394 K(250°F)	16.48(2390)		10% Adhesive
Rubber		16.27(2360)	Avg.	
Protected with	296 K(73°F)	11.7(1690)		50% Adhesive
RTV Silicone		12.5(1820)		50% Adhesive
Rubber		12.1(1760)	Avg.	

Specimens Conditioned 42 days at 355 K (180°F)/97% RH

Specimen Design	Test Temperature °K(°F)	Shear Strength MPa(psi)		Type of Failure
Unprotected	394 K(250°F)	2.48(360)		100% Adhesive
		2.27(330)		100% Adhesive
		2.38(345)	Avg.	
Protected with		6.96(1010)		75% Adhesive
RTV Silicone	394 K(250°F)	5.65(820)		75% Adhesive
Rubber		5.65(820)		75% Adhesive
		7.38(1070)		75% Adhesive
		6.4 (930)	Avg.	
Unprotected	296 K(73°F)	6.0 (870)		100% Adhesive
Protected with	296 K(73°F)	6.62(960)		75% Adhesive
RTV Silicone		7.24(1050)		75% Adhesive
Rubber	6.93(10( )	6.93(1005)	Avg.	

Protected Specimen — Specimen Design ASTM D1002-72

Bondline Thickness

RTV Bead — 0.0076 cm(0.003 in.)

The low test values of the moisture conditioned specimens indicated that the bond strength of the titanium shoes to the specimen would be inadequate to withstand the applied stress during the spin test. The Task IV spin tests were, therefore, eliminated from the program. General Electric has demonstrated, during the execution of the Air Force F103 Composite Blade Program Contract F33615-74-C-5072, good correlation between whirligig dynamic impact damage and static testing of the same airfoil. Therefore, it is believed that the Tasks II and III static testing yielded sufficient technical data to fulfill the aims of this program.

One Task IV specimen was completely finalized with titanium bonded shoes before the decision was made to eliminate the whirligig rig tests. Figure 99 shows Specimen S/N SPIII-6 with the titanium shoes bonded to the specimen to form the rig attachment feature.

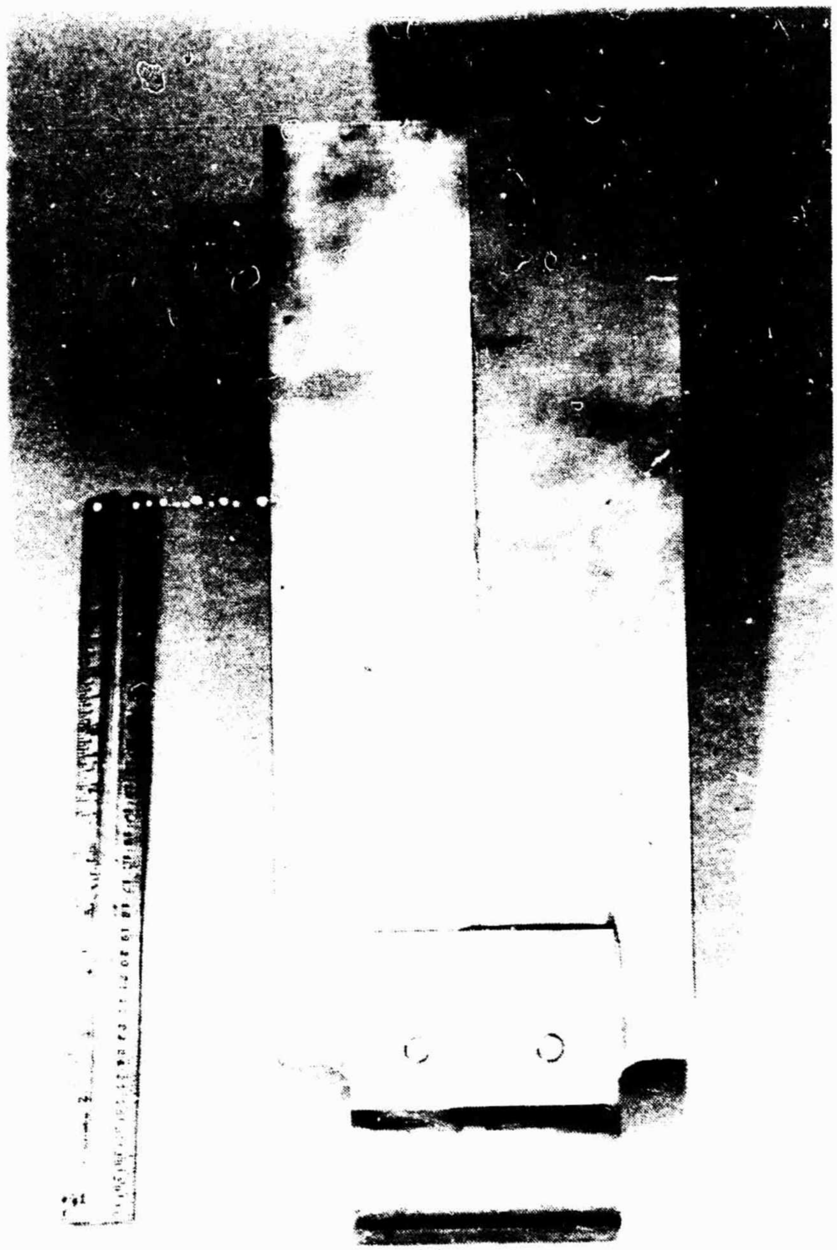


Figure 99. Task IV Specimen with Bonded Titanium Rig Adaptor Shoes.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based upon the results obtained during the execution of the Tasks I, II, and III, the following conclusions were made:

- The program demonstrated the superior impact resistance of the superhybrid concept for composite fan blades at both 294 K and 394 K test temperatures and when environmentally conditioned to a fully moisture saturated state ("wet") and when subjected to an abrupt temperature excursion in a saturated condition ("wet spike").
- The titanium outer foil layer used in the superhybrid construction acts as a moisture barrier thereby preventing moisture degradation of the underlying foil bonding adhesives and the polymeric composite core materials.
- The lower temperature capability polymeric composite systems are adversely affected by full moisture saturation when tested at temperatures near the resin glass transition temperature (Tg). The moisture plasticizes the resin matrix lowering the temperature capability of the composited system.
- Moisture absorbed, at ambient conditions (294 K/50% RH) by T300 graphite reinforced composites, using the three selected matrix materials, does not affect the mechanical properties.
- NR150A2 composite materials absorb only thirty percent of the moisture saturation of the two epoxy systems.
- NR150A2 composite systems exhibit superior transverse flexural properties in unidirectional laminates resulting in improved impact resistance compared to the epoxy matrix systems evaluated.
- The leading edge protection device failed prematurely in Task III due to the moisture sensitivity of the Metlbond 328 used for bonding the wire mesh nickel plating substrate.
- A large percentage of the cantilever supported impacted specimens exhibited local cracking in the zone of the support clamp.

Recommendations

- The superhybrid concept for fan blade applications is worthy of further development. The impact testing conducted in this program reinforced the findings in the previous NASA program conducted by General Electric, Program NAS3-20402 "Metal Spar/Superhybrid Shell Composite Fan Blades."

- Future impact testing of simulated airfoil specimens should be conducted using the free-free method of "support" to eliminate the overshadowing effect of specimen cracking at the clamp in the cantilever support method used in the program.

- Although the program illustrated the adverse effects of moisture on polymeric composite material properties, in true life environmental conditions, the components do not reach full saturation. Small amounts of absorbed moisture have little effect on composite properties. In future studies it is recommended that the true service conditions be evaluated for the particular composite component to determine the realistic degree of moisture saturation likely to be encountered. In order to typify this recommendation, we refer to some in-house work conducted at General Electric in determining the moisture saturation level required for a material design criteria study for a composite design thrust reverser.

A typical mission cycle was devised for the CF6-50 Thrust Reverser (Figure 100a) which is believed to be an exaggerated case of an aircraft continuously operating out of Miami, Florida during the summer season where aircraft skin temperatures of 333 K(140° F) and accompanying 97% relative humidity conditions have been recorded.

Nine different candidate resin/fiber reinforcement combinations were evaluated using 12.8 cm x 15.24 cm x 25mm (5 in. x 6 in. x 0.10 in.) laminates.

- Resins[450 K(350° F) Systems]
  - Fiberite 976
  - Ferro CE9000-2
  - Cyanamid BP980
- Fiber Reinforcements
  - 120 Style E-glass fabric
  - T300 24 x 24 Style fabric
  - Kevlar 285 Style fabric

The test panels were initially subjected to six days at 333 K(140° F)/97% relative humidity simulating an aircraft inoperative on the ground prior to conducting 10 typical mission cycle exposures. Each mission cycle consisted of a thermal spike of 394 K(250° F) for five minutes to simulate maximum takeoff temperature likely to be encountered by the thrust reverser followed by conditioning at 218 K(-67° F) for two hours under partial vacuum simulating flight conditions at 40,000 feet altitude. The panels then were subjected to 333 K(140° F)/97% relative humidity for one hour to be representative of the aircraft grouded between flights. Figure 100b graphically illustrates the

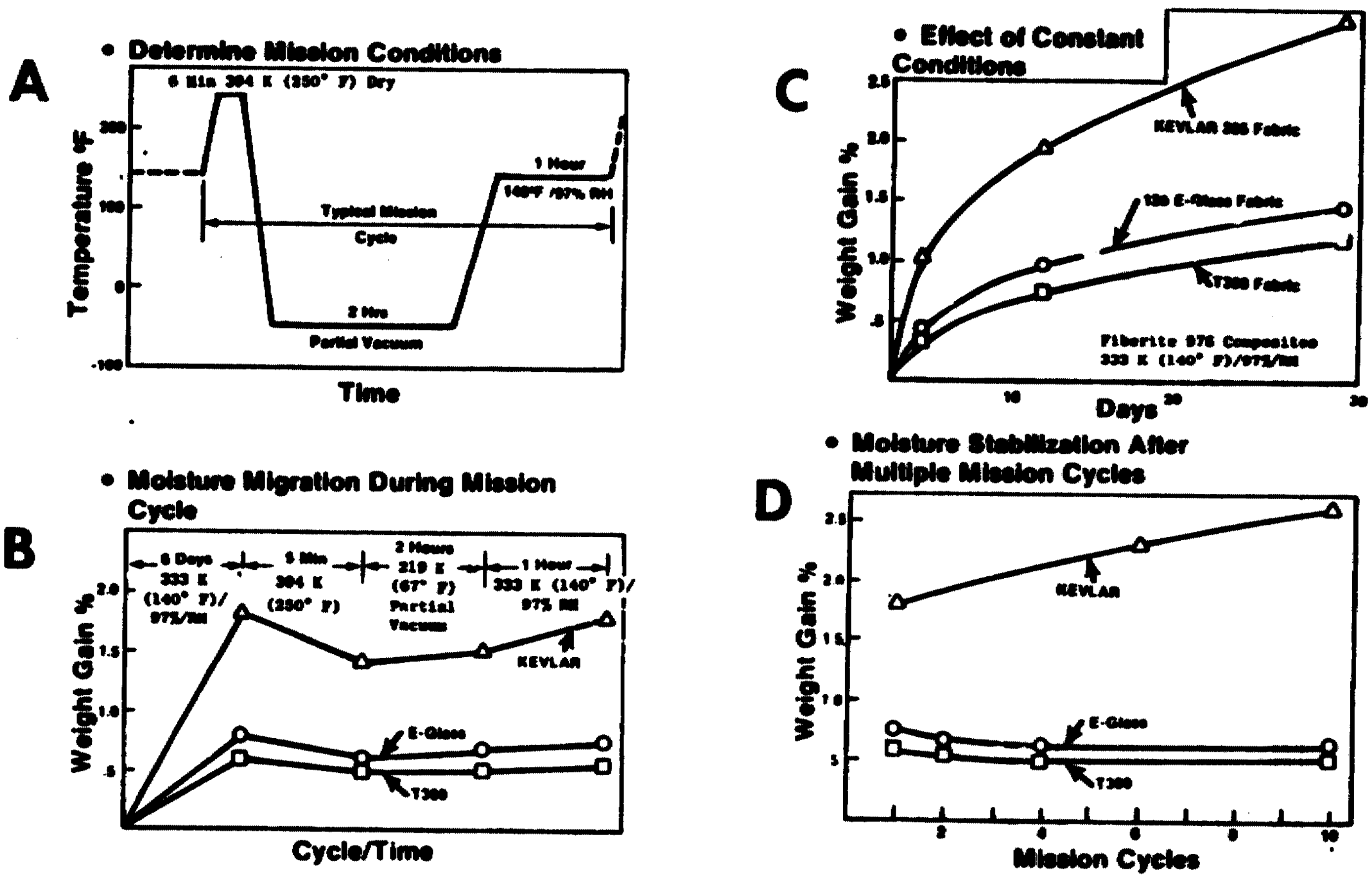


Figure 100. Determination of True Moisture Level in Composites Under Service Conditions.

typical absorption/desorption which occurs during the first cycle due to initial moisture conditioning/heating and drying out on the Fiberite 976 laminates. Typical moisture absorption curves for the three reinforcements combined with the Fiberite 976 resin system and exposed to constant 333 K(140° F)/97% relative humidity are shown in Figure 100c. The effect of the multiple mission cycles on the moisture content of the laminates are shown in Figure 100d. The T300 graphite and the E-glass fabric reinforced laminates normalized after 3/4 cycles to a constant approximate 0.6 weight gain. The Kevlar 49 fabric laminate continued to absorb moisture under typical mission exposure conditions until a fully saturated level was attained. Unlike graphite and glass, the basic Kevlar fiber absorbs moisture in addition to the resin matrix. DuPont data indicates that the bare Kevlar fiber absorbs moisture at the rate of 0.3 percent per hour and finally reaches a saturation level of approximately 3 percent weight gain at 294 K(70° F)/55 percent relative humidity conditions.

Based upon the results of the study, the moisture environmental conditioning plan for developing materials characterization design criteria was compiled.

Unlike the thrust reverser application where it is exposed to the natural elements of rain and absorbed heat from the sun, a majority of the potential applications for composites in the aero propulsion engines are sheltered inside the engine cowlings. The internal components, however, will be subjected to humidity at ambient temperatures during storage and inoperative time on the ground in addition to the flight temperature parameters and mission cycles and therefore, moisture levels in the composites need to be determined for each specific application to evaluate correctly the effect on mechanical and physical properties.

- Leading edge protection systems for composite fan blades need further studies. The high shear and peel stresses induced at the bond between the protection and the substrate during impact are too severe for conventional adhesives. High strain response films with high elongation and viscoelastic damping characteristics are required to withstand the high stresses without failure. The polyurethane film adhesive evaluated showed considerable promise in being able to withstand severe deformation without failure. A more heat and moisture resistant elastomeric film is required for this application.

FINAL REPORT DISTRIBUTION LIST, CR 165211

NAS 3-21017

ENVIRONMENTAL EFFECTS ON FOD RESISTANCE

OF COMPOSITE FAN BLADES

	Copies
Advanced Research Projects Agency Washington, D.C. 20525	
Attn: Library	1
Advanced Technology Center, Inc. LTV Aerospace Corporation P.O. Box 6144 Dallas, TX 75222	
Attn: D. H. Petersen	1
W. J. Renton	1
Air Force Flight Dynamics Laboratory Wright-Patterson Air Force Base, OH 45433	
Attn: G. P. Sendeckyj (FBC)	1
R. S. Sandhu	1
Air Force Materials Laboratory Wright-Patterson Air Force Base, OH 45433	
Attn: H. S. Schwartz (LN)	1
T. J. Reinhart (MBC)	1
G. P. Peterson (LC)	1
E. J. Morrisey (LAE)	1
S. W. Tsai (MBM)	1
N. J. Pagano	1
J. M. Whitney (MBM)	1
Air Force Office of Scientific Research Washington, D.C. 20333	
Attn: J. F. Masi (SREP)	1
Air Force Office of Scientific Research 1400 Wilson Boulevard Arlington, VA 22209	1

Copies

AFOSR/NA
Bolling Air Force Base, D.C. 20332

Attn: A. Amos 1

Babcock & Wilcox Company
Advanced Composites Department
P.O. Box 419
Alliance, OH 44601

Attn: P. M. Leopold 1

Bell Helicopter Company
P.O. Box 482
Ft. Worth, TX 76101

Attn: H. Zinberg 1

The Boeing Company
Vertol Division
Morton, PA 19070

Attn: R. A. Pinckney 1
E. C. Durchlaub 1

Battelle Memorial Institute
Columbus Laboratories
505 King Avenue
Columbus, OH 43201

Attn:
L. E. Hulbert 1

Brunswick Corporation
Defense Products Division
P.O. Box 4594
43000 Industrial Avenue
Lincoln, NE 68504

Attn: R. Morse 1

Commander
Naval Air Systems Command
U.S. Navy Department
Washington, D.C. 20360

Attn: M. Stander, AIR-43032D 1

	Copies
Commander Naval Ordnance Systems Command U.S. Navy Department Washington, D.C. 20360	
Attn: B. Drimmer, ORD-033	1
M. Kinna, ORD-033A	1
Cornell University Department Theoretical & Applied Mechanics Thurston Hall Ithaca, NY 14853	
Attn: S. L. Phoenix	1
Defense Metals Information Center Battelle Memorial Institute Columbus Laboratories 505 King Avenue Columbus, OH 43201	1
Department of the Army U.S. Army Aviation Materials Laboratory Ft. Eustis, VA 23604	
Attn: I. E. Figge, Sr.	1
Library	1
Department of the Army U.S. Army Aviation Systems Command P.O. Box 209 St. Louis, MO 63166	
Attn: R. Vollmer, AMSAV-A-UE	1
Department of the Army Plastics Technical Evaluation Center Picatinny Arsenal Dover, NJ 07801	
Attn: H. E. Pebly, Jr.	1
Department of the Army Watervliet Arsenal Watervliet, NY 12189	
Attn: G. D'Andrea	1

Copies

Department of the Army
Watertown Arsenal
Watertown, MA 02172

Attn: A. Thomas 1

Department of the Army
Redstone Arsenal
Huntsville, AL 35809

Attn: R. J. Thompson, AMSMI-RSS 1

Department of the Navy
Naval Ordnance Laboratory
White Oak
Silver Springs, MD 20910

Attn: R. Simon 1

Department of the Navy
U.S. Naval Ship R&D Laboratory
Annapolis, MD 21402

Attn: C. Hersner, Code 2724 1

Director
Deep Submergence Systems Project
6900 Wisconsin Avenue
Washington, D.C. 20015

Attn: H. Bernstein, DSSP-221 1

Director
Naval Research Laboratory
Washington, D.C. 20390

Attn: Code 8430
I. Wolock, Code 8433 1

Drexel University
32nd and Chestnut Streets
Philadelphia, PA 19104

Attn: P. C. Chou 1
W. Wang 1

E. I. duPont DeNemours & Company
duPont Experimental Station
Wilmington, DE 19898

Attn: C. H. Zweben 1

	Copies
Fiber Science, Inc. 245 East 157th Street Gardena, CA 90248	
Attn: E. Dunahoo	1
General Dynamics P.O. Box 748 Ft. Worth, TX 76100	
Attn: D. J. Wilkins	1
Library	1
General Dynamics/Convair P.O. Box 1128 San Diego, CA 92112	
Attn: J. L. Christian	1
General Electric Company Evendale, OH 45215	
Attn: C. Stotler	1
R. Ravenhall	1
S. Mitchell	1
General Motors Corporation Detroit Diesel-Allison Division Indianapolis, IN 46244	
Attn: M. Herman	1
Georgia Institute of Technology School of Aerospace Engineering Atlanta, GA 30332	
Attn: L. W. Rehfield	1
Grumman Aerospace Corporation Bethpage, Long Island, NY 11714	
Attn: S. Dastin	1
J. B. Whiteside	1
Hamilton Standard Division United Aircraft Corporation Windsor Locks, CT 06096	
Attn: W. A. Percival	1

Copies

Hercules, Inc.
Allegheny Ballistics Laboratory
P.O. Box 210
Cumberland, MD 21053

Attn: A. A. Vicario 1

Hughes Aircraft Company
Culver City, CA 90230

Attn: A. Knoell 1

Illinois Institute of Technology
10 West 32nd Street
Chicago, IL 60616

Attn: L. J. Broutman 1

IIT Research Institute
10 West 35th Street
Chicago, IL 60616

Attn: I. M. Daniel 1

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103

Attn: Library 1

Lawrence Livermore Laboratory
P.O. Box 808, L-421
Livermore, CA 94550

Attn: T. T. Chiao 1
E. M. Wu 1

Lehigh University
Institute of Fracture & Solid Mechanics
Bethlehem, PA 18015

Attn: G. C. Sih 1

Lockheed-Georgia Company
Advanced Composites Information Center
Department 72-14, Zone 402
Marietta, GA 30060

Attn: T. M. Hsu 1

Lockheed Missiles and Space Company
P.O. Box 504
Sunnyvale, CA 94087

Attn: R. W. Fenn 1

	Copies
Lockheed-California Burbank, CA 91503	
Attn: J. T. Ryder	1
K. N. Lauraitis	1
J. C. Ekvall	1
McDonnell Douglas Aircraft Corporation P.O. Box 516 Lambert Field, MS 63166	
Attn: J. C. Watson	1
McDonnell Douglas Aircraft Corporation 3855 Lakewood Boulevard Long Beach, CA 90810	
Attn: L. B. Greszczuk	1
Material Sciences Corporation 1777 Walton Road Blue Bell, PA 19422	
Attn: B. W. Rosen	1
Massachusetts Institute of Technology Cambridge, MA 02139	
Attn: F. J. McGarry	1
J. F. Mandell	1
J. W. Mar	1
NASA-Hugh L. Dryden Flight Research Center P.O. Box 273 Edwards, CA 93523	
Attn: Library	1
NASA-George C. Marshall Space Flight Center Huntsville, AL 35812	
Attn: C. E. Cataldo, EH01	1
Library	1
C. E. Lifer, EP41	1
NASA-Goddard Space Flight Center Greenbelt, MD 20771	
Attn: Library	1

Copies

NASA-Langley Research Center
Hampton, VA 23665

Attn:	C. Blankenship MC 188a	1
	R. A. Pride, MC 188a	1
	M. C. Card, MC 230	1
	J. R. Davidson, MC 188E	1

NASA-Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135

Attn:	Contracting Officer, MS 501-11	1
	Tech. Report Control, MS 5-5	1
	Tech. Utilization, MS 3-19	1
	AFSC Liaison, MS 501-3	1
	Structures & Mechanical Tech.Div. File, M.S. 49-6	1
	T. W. Orange, MS 49-6	1
	R. F. Lark, MS 500-202	1
	R. H. Johns, MS 49-6	1
	C. C. Chamis, MS 49-6	1
	Library, MS 60-3	1
	G. T. Smith, MS 49-6	5

NASA-Lyndon B. Johnson Space Center
Houston, TX 77001

Attn:	S. Glorioso, ES5	1
	Library	1
	R. G. Forman, ES5	1

NASA Scientific and Technical Information Facility
P.O. Box 33
College Park, MD 20740

Attn:	Acquisitions Branch	19

National Aeronautics and Space Administration
Office of Advanced Research & Technology
Washington, D.C. 20546

Attn:	L.A.Harris Code RWS-3	1
	D.J.Weldman Code RW-3	1

National Aeronautics and Space Administration
Office of Technology Utilization
Washington, D.C. 20546 1

	Copies
National Science Foundation Engineering Division 1800 G. Street, NW Washington, D.C. 20540	
Attn: Library	1
Northrop Space Laboratories 3401 West Broadway Hawthorne, CA 90250	
Attn: R. M. Verette	1
G. C. Grimes	1
Pratt & Whitney Aircraft East Hartford, CT 06108	
Attn: R. F. Liss	1
Rockwell International Los Angeles Division International Airport Los Angeles, CA 90009	
Attn: L. M. Lackman	1
D. Y. Konishi	1
Sikorsky Aircraft Division United Aircraft Corporation Stratford, CT 06602	
Attn: Library	1
Southern Methodist University Dallas, TX 75275	
Attn: R. M. Jones	1
Southwest Research Institute 8500 Culebra Road San Antonio, TX 78284	
Attn: P. H. Francis	1
Space & Missile Systems Organization Air Force Unit Post Office Los Angeles, CA 90045	
Attn: Technical Data Center	1

Copies

Structural Composites Industries, Inc.
6344 N. Irwindale Avenue
Azusa, CA 91702

Attn: R. Gordon 1

Texas A&M
Mechanics & Materials Research Center
College Station, TX 77843

Attn: R. A. Schapery 1

TRW, Inc.
23555 Euclid Avenue
Cleveland, OH 44117

Attn: I. Toty 1

Union Carbide Corporation
P.O. Box 6116
Cleveland, OH 44101

Attn: J. C. Bowman 1

United Technologies Research Center
East Hartford, CT 06108

Attn: R. C. Novak 1
A. J. Dennis 1

University of Dayton Research Institute
Dayton, OH 45409

Attn: R. W. Kim 1

University of Delaware
Mechanical & Aerospace Engineering
Newark, DE 19711

Attn: B. R. Pipes 1

University of Illinois
Department of Theoretical & Applied Mechanics
Urbana, IL 61801

Attn: S. S. Wang 1

University of Oklahoma
School of Aerospace Mechanical & Nuclear Engineering
Norman, OK 73069

Attn: C. W. Bert 1

Copies

University of Wyoming
College of Engineering
University Station Box 3295
Laramie, WY 82071

Attn: D. F. Adams 1

U.S. Army Materials & Mechanics Research Center
Watertown Arsenal
Watertown, MA 02172

Attn: E. M. Lenoe 1
D. W. Oplinger 1

V.P.I. and S.U.
Department of Engineering Mechanics
Blacksburg, VA 24061

Attn: R. H. Heller 1
H. J. Brinson 1
C. T. Herakovich 1
L. Reifsnider 1

ARRADCOM
Plastics Technical Evaluation Center
Dover, NJ 07801 1

Aerojet Liquid Rocket Company
P. O. Box 13222 Sacramento, CA 95813
Attn: J. Wilkening
Dept. 8300.,Bldg. 2001 1

Westinghouse Electric Corp.
P.O. Box 9175
Philadelphia, PA 19113
Attn: Hillary Johnson

Library N203 1